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# HOME STUDY COURSE
# IN
# PRACTICAL ELECTRICITY

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IN

# Practical Electricity

## AN ELECTRICAL CATECHISM

*IN THREE VOLUMES*

VOLUME II
ELECTRICAL CONTROL, MEASUREMENT AND WIRING

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# TRANSFORMERS

## FUNDAMENTAL PRINCIPLES

**426. What is a transformer?**

An apparatus used for changing the voltage of alternating current. A transformer thus affords a means of raising the voltage of alternating-current generators for delivery to transmission lines, and of obtaining low-voltage current from high-voltage transmission lines.

**427. Why is it desirable to use high voltage on the transmission lines?**

It is advantageous to operate transmission circuits at high voltage because this saves expense in the construction of the circuits by permitting the use of small conductors.

Suppose 10,000 kilowatts must be transmitted at 3000 volts over an alternating-current system the power factor of which is 80 per cent. With single-phase transmission, the current $I$ equals the power in watts $W$ divided by the voltage $E$ times the power factor $P$, that is, $I = \frac{W}{E \times P}$, or substituting values, $I = \frac{10{,}000{,}000}{3000 \times 0.80} = 4167$ amperes. To carry this current there would be required two cables in multiple, of about 2,500,000 c.m. each, on both sides of the transmission circuit, and for a line much over a quarter of a mile in length the cost of the copper conductors would be prohibitive.

If, however, the voltage be raised to 60,000, or twenty times the above value, the line current will be one-twentieth, which is $4167 \div 20 = 208$ amperes. This current could be carried by a No. 00 wire on both sides of the transmission circuit. The saving in copper over a line of any appreciable length, due to the higher voltage, would therefore many times

over pay for the necessary transformers and high-voltage line equipment.

**428. Why is it necessary to use transformers to raise the voltage for transmission purposes?**

Because generators cannot be built to operate reliably at the high voltages required for long transmission lines. In order to keep the cost of very long lines within commercial limits the voltages are carried up as high as 60,000 volts, and generator armatures cannot yet be insulated to withstand any such pressure, or even 25,000 volts.

**429. Why must the high voltage on the transmission lines be changed into low-voltage current?**

Because the usual voltage on the transmission line is much too high for safe distribution to users of current; hence transformers are interposed to obtain current at safe pressures.

**430. Are designating names given to transformers to distinguish those that increase voltages from those that are used to decrease them?**

Yes; the former are called step-up transformers and the latter step-down transformers. Referring to Fig. 118, the

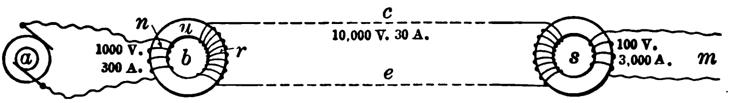



Fig. 118.—Illustration of the Use of Transformers, the Figures given being based on No Loss in Line or Transformers, and Power Factor 1.

step-up transformer *b* raises the voltage supplied to it by the alternator *a* for transmission over the line *c e*. The step-down transformer *s* lowers the line voltage for use in lamps, motors, etc., connected to the circuit *m*.

**431. Describe the general construction and the principles of operation of a transformer.**

A transformer consists essentially of two windings so placed on a soft iron core that the inductive action of the one upon the other is very great. Taking, for example, the

transformer *b*, Fig. 118, one of the windings *n* is joined to the source of power and is called the primary winding. The alternating current flowing through this winding produces an alternating flux or flow of magnetic lines of force in the iron ring *u*, and these cutting the other winding *r*, which is called the secondary winding, induce in it an alternating electromotive force.

**432. Is there any fixed relation between the voltage applied to the primary winding of a transformer and that induced in the secondary winding?**

Yes; the voltage induced in the secondary winding is always in direct proportion to that in the primary winding. If both primary and secondary windings are composed of the same number of turns of wire, the voltage induced in the secondary winding will be practically equal to that applied to the primary winding. If, however, the secondary winding consists of one-half as many turns as are in the primary winding, the secondary voltage will be half that of the primary, and the transformer will be of the step-down type. If the secondary winding consists of twice as many turns as are in the primary winding, the secondary voltage will be twice that of the primary, and the transformer will be of the step-up type. In a step-down transformer of the ratio mentioned, the current in the secondary winding will be approximately twice that in the primary, and in the step-up transformer of the ratio mentioned, the current in the secondary will be approximately one-half as great as that in the primary, providing in both cases the resistances of the primary and secondary circuits are equal.

## TRANSFORMER LOSSES

**433. Is there any loss in a transformer?**

Yes; there are losses due to three causes: the resistance of the windings, the opposition (called "hysteresis") that the iron in the core offers to the rapid changes in the magnetism which the primary current produces in it, and the

induction of eddy currents in the core in the same way that current is induced in the secondary winding.

**434. What means are taken to keep down the resistance loss in the windings?**

The length of wire per turn is made as small as possible and, as the resistance of the windings is increased by an increase in their temperature, special means are taken to provide ample radiation. Although in some transformers the heat developed is carried off by a natural draft, in many of them the coils and core are immersed in oil, the oil acting as a medium to conduct the heat from the coils to the surrounding case or tank. If there is sufficient space inside the case, the oil will circulate of itself, the cooler oil rising as it becomes more and more heated, and the hot oil on the top descending as it becomes cooled by contact with the inside surface of the case. The efficiency of the case for cooling the oil may be made greater by corrugating it, thereby increasing its radiating surface.

In transformers of very large capacity artificial means are provided for cooling the oil. In some of these the heated oil is cooled by coming in contact with pipes through which cold water is circulated. In others, oil is forced through the cooling pipes, and in still others no oil is used, but ventilation and radiation of the heat are secured by forcing air through the coils and core.

**435. What means are taken to keep down the hysteresis loss?**

The core sheets are stamped from the softest iron obtainable and are worked at a low degree of magnetization.

**436. What means are taken to keep down the eddy current loss?**

The iron core is built up of very thin sheets of iron or steel, and these are insulated from each other by varnish or sheets of tissue paper, and are laid face to face at right angles to the path that the eddy currents tend to follow.

**437. What means are taken to prevent the high-voltage current in one winding from breaking into the other winding?**

Very high-resistance insulating materials are used between the coils, such as oiled silk, oiled linen, mica, fiber or micanite. The wires forming the coils are covered individually with several layers of cotton fiber. The oil used in transformers primarily for cooling them is also of advantage in preserving the insulation from oxidation, and in automatically re-insulating the material in case it becomes punctured.

**438. Upon what is the efficiency of a transformer based?**

The efficiency of a transformer may be expressed in terms of its full-load operation or in terms of its all-day operation. The full-load efficiency of a transformer is the ratio be-

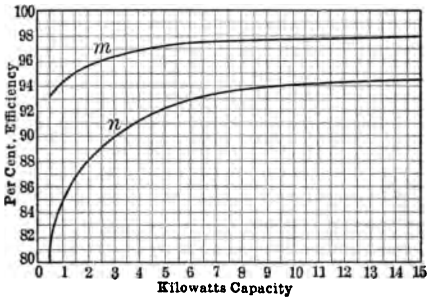



Fig. 119.—Efficiency Curves of a Transformer.

tween the watts supplied to the primary winding and those delivered by the secondary winding with a non-inductive load. In Fig. 119 at *m* is shown the full-load efficiency curve of a modern type of transformer.

The all-day efficiency of a transformer is the average of its efficiencies throughout the range of load supplied by the transformer during 24 hours. An all-day efficiency curve is shown at *n*, Fig. 119.

**439. With a constant primary voltage, does the secondary voltage of a transformer remain constant under different load conditions?**

No; as the load on the secondary circuit is increased, the secondary voltage drops. The drop of secondary voltage between no load and full load expressed as a percentage of the secondary voltage at no load is called the regulation of the transformer; its value should not exceed two per cent. for ordinary work.

**440. What causes the drop in secondary voltage as the load increases?**

The resistance of the windings. The greater the current passing through them the greater will be the voltage necessary to force that current through. This voltage is taken from the secondary voltage, leaving less pressure available for useful work outside.

## TRANSFORMER CONNECTIONS

**441. Is a transformer ever wound so that it can be connected to circuits of different voltages?**

Yes; some transformers have two primary windings, which may be connected either in parallel or series so that the same transformer can be used either on a 1000-volt circuit or a 2000-volt circuit. In the former case the primary coils would be connected in parallel, and in the latter case in series.

**442. Are transformers ever connected in series or in parallel with each other?**

Very seldom in series, because there is no difficulty in building them for any voltage now employed, and the first cost is less than if two or more transformers were used in place of one. Transformers are often used in parallel so that each of them may be worked at full load and consequently at highest efficiency.

**443. Must transformers conform to any special requirements in order to work well in parallel?**

Yes; they should be of similar design and size, their percentage of regulation at full load must be the same and the secondary terminals connected together should have the same instantaneous polarities.

**444. How are the instantaneous polarities of the secondary terminals of transformers ascertained?**

The actual polarities need not be ascertained. By temporarily joining with a fusible wire two of the secondary ter-

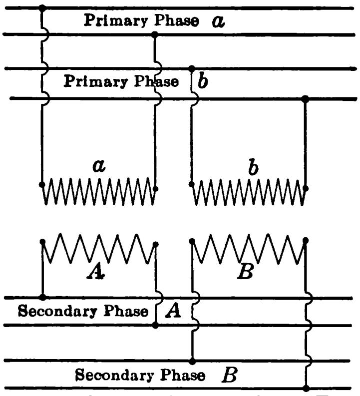



Fig. 120.—Connection of Transformers in a Two-Phase, Four-Wire System.

minals of the transformers to be connected together, exciting the primary windings and bringing together the two remaining terminals; if the fusible wire melts it proves that the polarities of the terminals joined together were not the same, and that the connections should be reversed; whereas, if the wire does not melt, it shows that the polarities are the same and that the temporary connections may be made permanent.

**445. How many transformers are required in a two-phase four-wire system, and how are they connected?**

Two transformers are required, one in each phase, connected as shown in Fig. 120. Here *a* and *A* are the primary

and secondary windings, respectively, of one of the transformers, and *b* and *B*, respectively, the primary and secondary windings of the other transformer.

**446. How many transformers are used for the two-phase three-wire system, and how are they connected?**

Two transformers are used as before, but as shown in Fig. 121 they are connected somewhat differently. The primary windings of the two transformers are connected together and the common conductor *m* of the three-wire system runs to their junction. The secondary windings are connected to the secondary three-wire circuit in a similar manner.

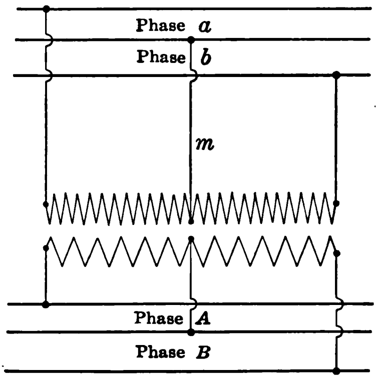



Fig. 121.—Connection of Transformers in a Two-Phase, Three-Wire System.

**447. In Fig. 121, what is the relation between the secondary voltage across the two outside wires and that between either outside wire and the center wire?**

The voltage between the two outside wires is 1.414 times that between either outside wire and the center wire.

**448. How many transformers are required for the three-phase star-connected system, and how are they arranged?**

Three transformers are used, connected up as indicated in Fig 122. Here *a*, *b* and *c* are the primary windings of the

three transformers, and *A, B* and *C* the corresponding secondary windings. One of the terminals of each primary winding is brought to a common connection and one of the terminals of each secondary winding is brought to another common connection; the three remaining terminals of the

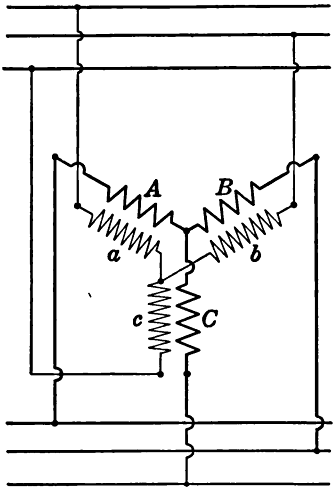



Fig. 122.—Connection of Transformers in a Three-Phase Star System.

primary and secondary windings are connected respectively to the primary and the secondary circuit wires.

**449. How many transformers are required for the three-phase mesh system, and how are they connected?**

Three transformers are used, connected as shown at Fig. 123. As before, *a, b* and *c* are the respective primary windings of the three transformers, and *A, B* and *C* the respective secondary windings. Their connections to the primary and secondary circuits are obvious from the illustration.

**450. Has either the star or the mesh connection of transformers any material advantage over the other?**

The star connection has an advantage over the mesh connection that each primary transformer winding is subjected

to only 57.7 per cent. of the circuit voltage. For high-voltage transmission this feature of the star connection allows smaller transformers to be used than with the mesh connection, and the insulation has to withstand only 57.7 per cent. of the voltage; the cost is therefore less.

The mesh connection, on the other hand, has an advantage over the star connection where continuity of service is very necessary, because the disabling and removal of any

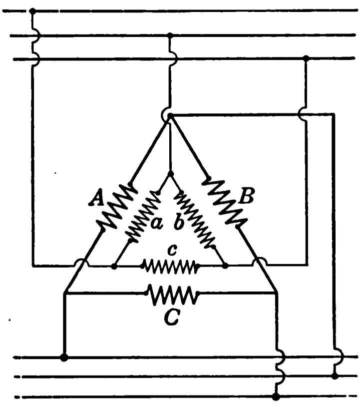



Fig. 123.—Connection of Transformers in a Three-Phase Mesh System.

one of the three transformers does not interrupt the three-phase distribution; even if two transformers are removed, reduced power may be transmitted single-phase fashion.

**451. Suppose three transformers, each with a ratio of transformation of 10 to 1, are connected star-fashion on a three-phase 1000-volt circuit, what voltages would be obtained from the secondary windings if they were connected mesh fashion?**

Since the secondary voltage would be 100 if both primary and secondary windings were connected up alike, and the ratio of mesh to star voltages at terminals is 0.577 to 1, the secondary voltages in the case mentioned will be but 57.7 volts.

**452. What secondary voltages would be obtained if the 10 to 1 transformers were connected with their primaries in mesh to a 1000-volt circuit and their secondaries in star relation?**

There would be induced in each secondary winding $100 \div 0.577 = 173.3$ volts.

**453. Can transformers be connected so as to deliver three-phase currents from a two-phase supply circuit, or vice versa?**

Yes; if the windings of the transformers be designed with this point in view. Referring to Fig. 124, *a* and *b* represent

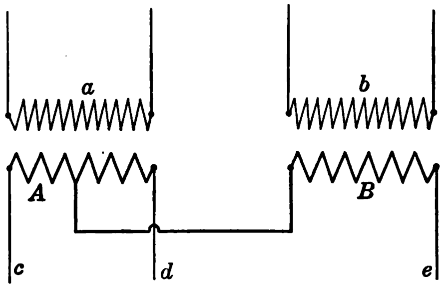



Fig. 124.—Connection of Transformers for obtaining Three-Phase Currents from a Two-Phase System.

the primary windings of two transformers connected to a two-phase four-wire circuit for the purpose of converting it into a three-phase circuit of the same or different voltage. The secondary winding *A* of the one transformer is wound in two equal sections so that each of them gives one-half of the required voltage in the secondary circuit. The secondary winding *B* of the other transformer is wound so as to give 0.866 times the required secondary voltage. At the three secondary terminals *c*, *d* and *e*, three-phase currents are delivered, and between any two of the three terminals the desired voltage exists.

By simply reversing the conditions in Fig. 124, currents from a three-phase system can readily be converted into two-

phase currents and delivered to a four-wire system at any required voltage.

## TYPICAL MODERN FORMS

**454. How may the typical modern forms of transformers be classified?**

Into three types, according to the method employed for cooling them: namely, oil-cooled transformers, water-cooled transformers and air-cooled transformers. Air-cooled transformers employing a forced draft are called air-blast transformers; otherwise, they are called self-cooled transformers.

**455. Illustrate and describe an oil-cooled transformer built for small loads.**

The oil-cooled transformer shown in Fig. 125, which is made by the General Electric Company in sizes ranging from

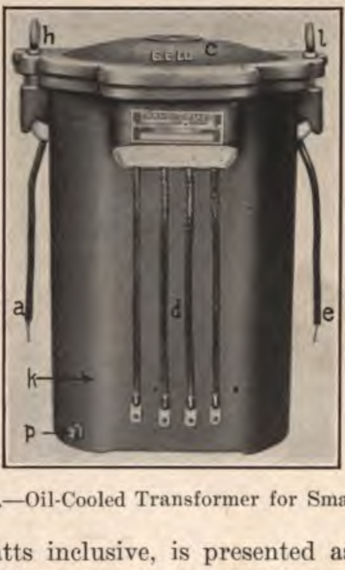



Fig. 125.—Oil-Cooled Transformer for Small Loads.

1 to 100 kilowatts inclusive, is presented as a common one of this type. The case or tank $k$ is of cast iron and is provided with a cover $c$, with gasket beneath to prevent the entrance of dust and moisture. The cover is clamped down on

the case by the eyebolts $h$ and $l$, which also serve as a means for lifting the transformer. A screw plug $p$ placed in a tapped hole at the lowest point of the case facilitates the drawing off of the oil inside; the primary leads are those at

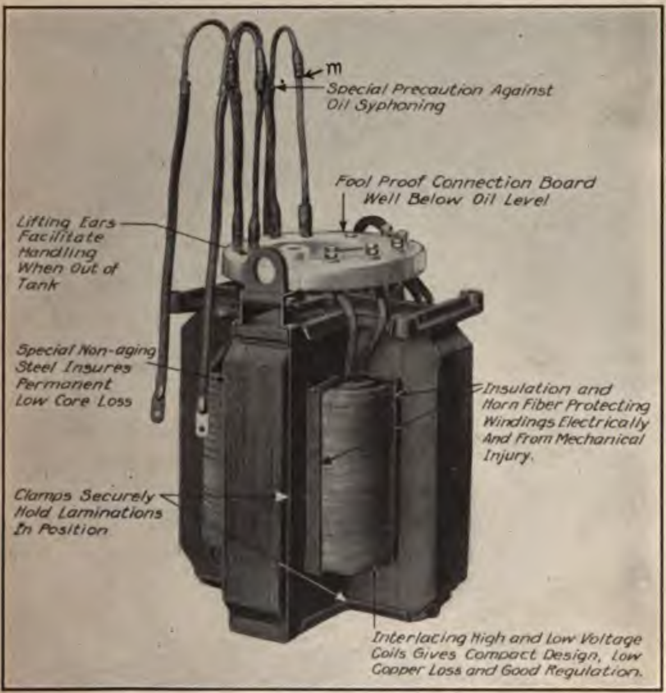



Fig. 126.—Working Parts of Transformer in Fig. 125, removed from Tank.

$a$ and $e$, and the secondary leads are shown at $d$, these latter being the terminals of two secondary coils which when joined in parallel enable 110 volts to be obtained from 2200 volts across the primary leads, and when connected in series enable 220 volts to be obtained from the 2200 volts on the primary. This transformer gives therefore a ratio of 20 : 1 or 10 : 1 according to the manner of connecting the secondary terminals.

The working parts, removed from the case, are shown in Fig. 126, and this illustration taken in connection with the plan of the core and windings in Fig. 127 should make plain the construction. The core is built up of sheet steel punchings so as to form four magnetic circuits of equal reluctance, in multiple, and are interlocked as shown to form a central

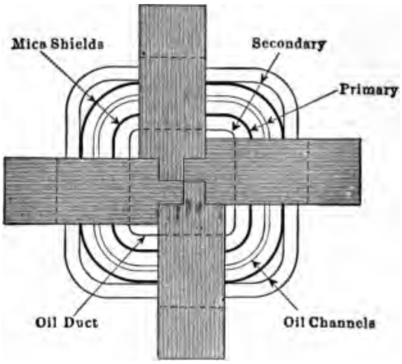



Fig. 127.—Plan of Core and Windings of Transformer in Fig. 125.

leg upon which the winding is placed. This construction gives a short mean length of turn in the winding as well as a short length of magnetic circuit in the core, resulting in low copper and core losses, high efficiency and good regulation. Free access is also afforded the oil to the parts of the coil and core. When the working parts are placed in the case, oil is poured in until it rises to a point *m* on the leads, Fig. 126.

**456. Is it advisable to make a ground connection to the secondary windings of the transformer?**

Grounding the secondaries of transformers has been approved by the American Institute of Electrical Engineers and the National Electric Light Association. The National Board of Fire Underwriters has incorporated in the National Electric Code rules covering this subject. To insure good service with a grounded secondary, superior insulation

between the primary and secondary is necessary, for the reason that, under these conditions only one ground, that is, one on the primary, is sufficient to put a strain of the full


Fig. 128.—Oil-Cooled Transformer for Loads up to 500 Kilowatts.

potential of the primary circuit on the insulation between primary and secondary coils, whereas ordinarily it requires an accidental ground on both primary and secondary. The grounding of the secondary is advisable, for then it is impos-

sible to obtain a difference of potential between the house wiring and the ground greater than the 110 or 220 volts of the lamp circuit. If a mica shield is used between the primary and secondary windings of the transformer, it makes the approved method of grounding perfectly safe.

**457. Illustrate and describe an oil-cooled transformer built for heavier loads than 100 kilowatts.**

Referring to Fig. 128, which shows a General Electric oil-cooled transformer built for loads up to about 500 kilo-

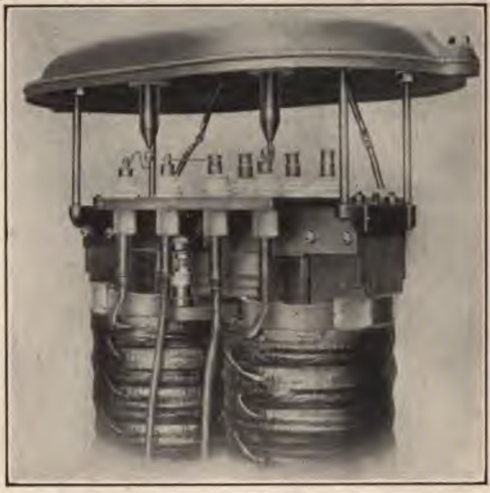


Fig. 129.—Inside Top Construction of Transformer in Fig. 128.

watts, the tank is made of sheet steel, corrugated as shown at *a* to increase the radiating surface without adding to the floor space or height. The ends of the tank are cast to a depth of one inch into a cast iron base *b* and rim *m*, resulting in a strong and oil-tight joint so that the tank is available for both indoor and outdoor service.

The oil outlet or drain *d* is a part of the base casting and is flush with the bottom of the tank, making it possible to drain off the oil completely. There are two large openings

in the cover, one for the high-tension leads *h* and *l*, and the other for the low-tension leads *n* and *v*, all of the leads being supported by bushings. The connection of the leads with the coils, and the construction of the latter and the core are shown in Fig. 129 for a 45,000-volt transformer. Both pri-

Fig. 130.—Water-Cooled Transformer with Oval Tank.

mary and secondary coils are wound on cylindrical forms, which are removed when the winding is completed, the coils baked and thoroughly insulated with tape, and then assembled on the core as shown in the illustration. All oil-cooled transformers over 100 kilowatts for indoor service are pro-

vided with mercury thermometers, as shown at *t* in Fig. 128, to indicate the temperature of the oil at the top of the transformer.

**458. Show a water-cooled transformer and describe its construction.**

The construction of water-cooled transformers is, in mechanical and electrical details, similar to the oil-cooled de-

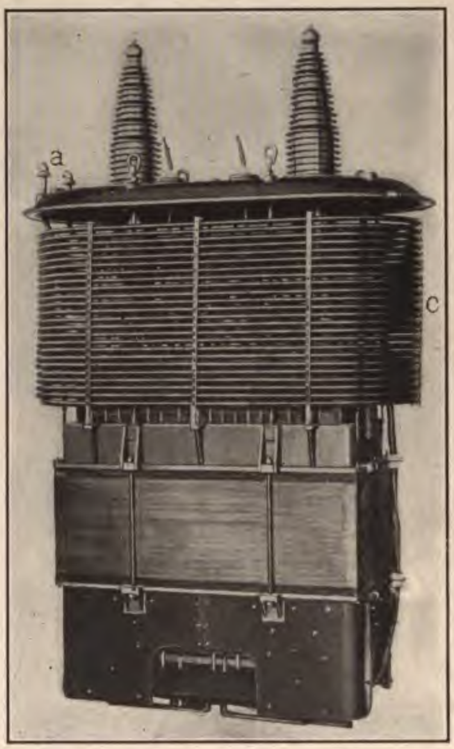



Fig. 131.—Interior of Transformer in Fig. 130, showing Location of Cooling Coil.

sign, the only difference being in the tank and the cooling coil. The tank of a 3000-kilowatt, 140,000-volt transformer is shown in Fig. 130. It is built of heavy boiler plate iron,

riveted to a cast iron base, and has an outlet pipe at *o* for draining out the oil.

The heat generated by losses in the transformer is disposed of by means of the circulation of water through coils of pipe placed in the hottest part of the oil. The location of the cooling coil is shown at *c*, Fig. 131; which illustrates the interior parts of the transformer in Fig. 130. So effective is the cooling coil that very little heat is dissipated from the tank and consequently there is no need of its being corrugated. The terminals *a* of the cooling pipe are connected respectively with the water supply and a drain, and during the operation of the transformer the water is supposed to be turned on.

Fig. 132.—Air-Blast Transformer.

**459. Illustrate and describe an air-blast transformer.**

A Westinghouse transformer of this type is shown in Fig. 132. It is designed for 550-kilowatt service with 13,200

volts on the high-tension leads and 395 volts on the low-tension leads, both these leads emerging from the bottom.

Air-blast transformers are cooled by a forced blast of air

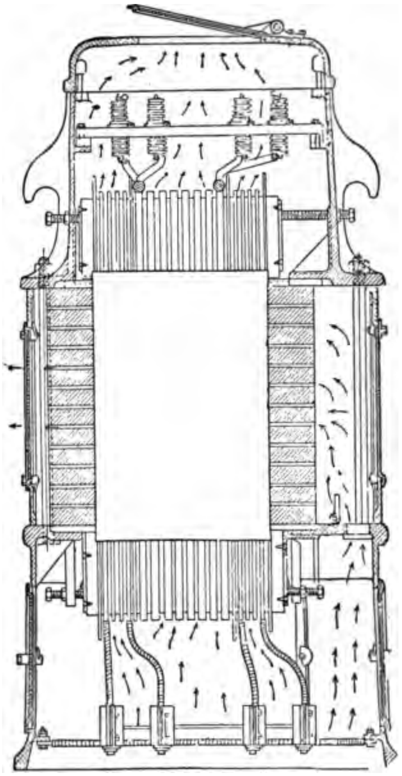


Fig. 133.—Longitudinal Section of Air-Blast Transformer, showing Air Ducts.

delivered by a blower. One electrically driven blower usually supplies all of the transformers in a station, although it is well to provide a duplicate blower equipment for emergencies. The transformers are generally placed above an air chamber in which a pressure is maintained slightly above that of the surrounding air, and the blower may deliver air

directly into this chamber, or, if it is more convenient, the blower can be located at a distance from the transformers, feeding into a conduit which leads to the air chamber.

The core and the coils are separately cooled, as shown in Fig. 133. The air for cooling the coils passes up through


Fig. 134.—Steps in the Building of a Coil for an Air-Blast Transformer.

the transformer between the coils, which are held apart by spacing strips, and discharges through an opening at the top of the transformer. This opening is provided with a damper for regulating the amount of air passing through the coils. The air for cooling the core passes from the lower housing through a damper at one side of the transformer, and then divides; a part going horizontally through ventilating ducts spaced at frequent intervals in the core while the remainder circulates around the outside of the core and joins the first stream at the outlet.

The blower for use with air-blast transformers should be selected to suit the transformer capacity, and to deliver a large volume of air at a low pressure, usually from $\frac{1}{2}$ to 1 oz., depending on the size of the transformer. The blower

is usually direct-connected to either an induction motor or a direct-current motor, but it can be driven by other means.

Both the high-tension and the low-tension coils of this transformer consist of thin flat coils. The high-tension coils are

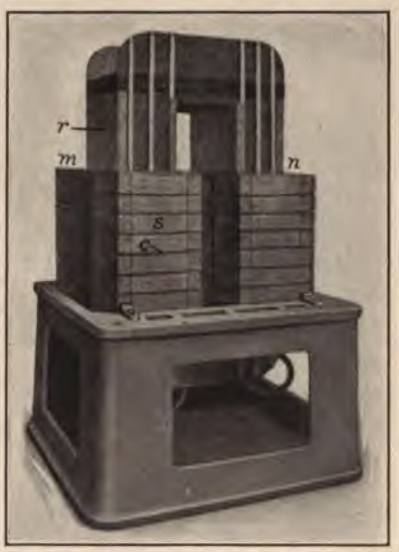



Fig. 135.—Partly Assembled Core of Air-Blast Transformer in Fig. 132, showing Ventilating Ducts and Coils.

usually wound with a flat copper ribbon, one turn per layer. These layers are separated from each other by a continuous strip of insulation, in addition to the cotton covering on the ribbon. The low-tension coils are wound and insulated in a similar manner to the high-tension coils. The conductors are of square or rectangular cross-section, and are wound flat, as shown in Fig. 134 at *A*. For heavy currents, two or more coils are bound together and connected in parallel, as at *B*, after which they are completely insulated together, as shown at *C*.

Turning, now, to Fig. 135, the high-tension and low-tension

coils, that is, the primary and secondary coils, are assembled together at *r* and the partly built-up core is shown at *m n*. The core is composed of thin sheet steel punchings laid on each other so as to form a nearly solid mass *s*, etc., and at regular intervals are separated by spacing blocks to provide ducts *c*, etc., through which the air blast is enabled to penetrate the interior of the core and insure a uniformly cool operation. The usual practice is to locate the high-tension terminals at the top and the low-tension terminals at the bottom of the transformer, although in the present case both are at the bottom, as previously noted.

**460. For what purposes are self-cooled transformers mostly used?**

For use in connection with electrical measuring instruments and other purposes requiring a comparatively small current. Self-cooled transformers are those in which the surrounding air is the direct means of absorbing the heat. They may be either potential transformers or current transformers.

**461. Show a potential transformer and state the usual capacities in which it is used with electrical measuring instruments.**

A potential transformer made by the Wagner Electric Manufacturing Company is shown in Fig. 136. It has two primary and four secondary leads, and a capacity of 25 watts. The primary leads are connected across the circuit in which the measurements are required, and the secondary leads are joined either in series or multiple with the meter. For voltmeter use, a capacity of 25 watts is sufficient; for power-factor indicator and voltmeter, 50 watts; for indicating or integrating wattmeter, 50 watts; for voltmeter, indicating and integrating wattmeter and power-factor indicator, 100 watts. These self-cooled potential transformers are wound for primary voltages of 220, 440, 1100 and 2200, and a secondary voltage of 110.

**462. Illustrate and describe a current transformer.**

A current transformer, sometimes called a series transformer because connected in series with the circuit from which the transformation is desired, is shown in Fig. 137. Its function is to transform the current rather than the voltage.

In this Wagner transformer the primary, denoted by *d*, is merely a straight conductor thoroughly insulated and con-

Fig. 136.—Self-Cooled Potential Transformer.

nected in the main circuit by means of the terminals *a* and *c*. The secondary winding encircles *d* in the case *m* and its leads are shown at *s*.

**463. Is there any special form of transformer other than those described, which is met with in practice?**

There is a constant-current transformer used to obtain an approximately constant direct-current for arc lamps in series connection. This is an air-cooled transformer, but is used in conjunction with a mercury arc rectifier for changing the alternating current into direct current, an exciting transformer for supplying a low-potential current to establish an arc in the rectifier in order to start it, and a direct-current reactance which is connected in series with the lamp

load to reduce the pulsations of the current for the lamps. The entire outfit, made by the General Electric Company, is shown in Fig. 138. It is there shown, with enclosing iron case removed, in the 50-light size, 2200-volt primaries and 4-ampere secondaries.

Referring to the constant-current transformer, its primary coils are shown at *c* and are stationary. The secondary coils *a* are movable up and down upon the iron core *d*, their weight


Fig. 137.—Self-Cooled Current Transformer.

being partially counterbalanced by the iron block *w*, to which they are connected by means of ropes *m*, etc., and the rocker arms at *n*. At normal full-load current the movable coils lie in contact with the stationary coils, notwithstanding the magnetic repulsion between them. When, however, one or more of the lamps are out of the circuit, the increasing current increases the repulsion between the coils, and separates them, reducing the current to normal. At minimum load, the distance between the coils is maximum. The regulation is thus entirely automatic, and maintains a practically constant current.

The exciting transformer which supplies a low potential for starting the rectifier is located at *p*. This establishes an arc when the rectifier tube is shaken, which is necessary to start it operating on the alternating current to change it to direct current. The rectifier tube consists of an exhausted

glass vessel containing a positive terminal in each of two upper arms, and a negative terminal of mercury at the bottom; it is submerged in oil, which is water-cooled in the tank

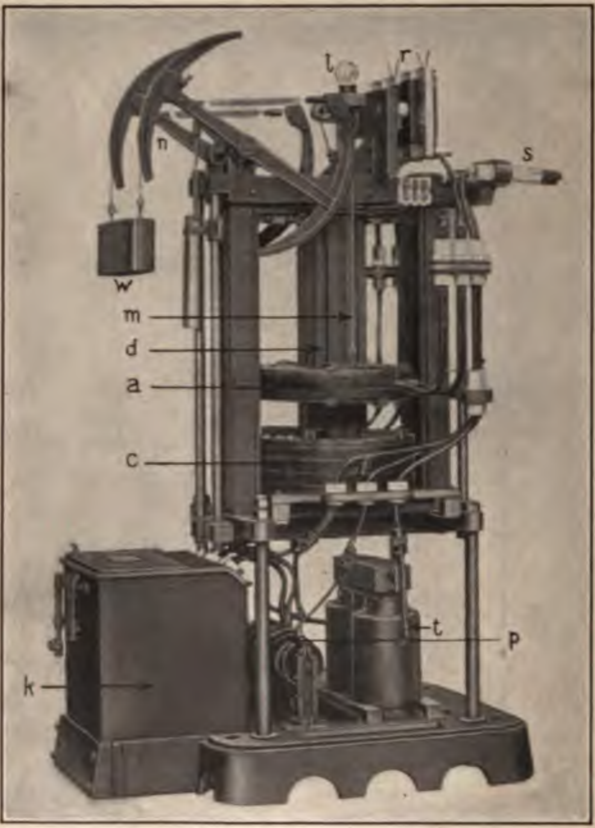



Fig. 138.—Constant-Current Transformer Outfit for Arc-Lamp Circuit.

*k*. The direct-current reactance is shown at *t*. The primary terminals for connection with a single-phase alternator may be seen at *s*, indicating lamps which are placed in series with the lamp load are shown at *l* and lightning arresters are provided at *r*.

# ELECTRICAL MEASUREMENTS AND INSTRUMENTS

## MEASUREMENT OF RESISTANCE

**464. Is there more than one method of measuring resistance?**

Yes; a different method must be used for measuring a low resistance from that which would be employed for measuring a high resistance if accurate results are to be obtained.

**465. What is the usual method of measuring a very low resistance?**

When the resistance to be measured does not exceed two or three ohms, the slide-wire bridge method is used.

**466. Describe the slide-wire bridge.**

The bridge itself, Fig. 139, consists of three heavy copper strips *A, C* and *D,* mounted on a board. Between the strips

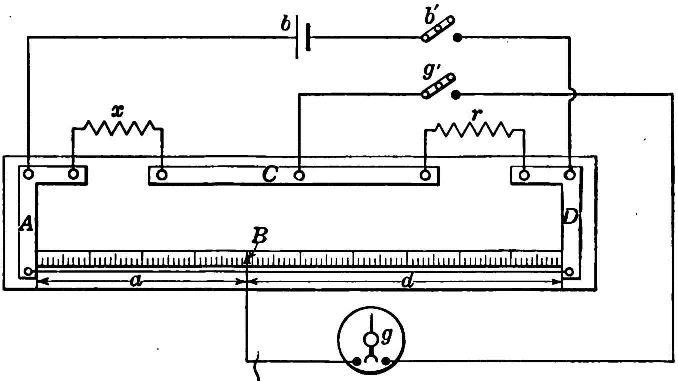



Fig. 139.—Connections of Slide-Wire Bridge.

*A* and *D* is stretched a wire, usually of German silver, which is chosen on account of its high resistance. This wire is soldered firmly to the strips *A* and *D*. Below the wire is

mounted a scale divided into 1000 equal parts. A slider *B* is arranged to move parallel to the wire, and has a contact piece or brush, which presses upon the wire. On the slider is fastened a pointer for indicating its position on the scale. The ends of the copper strips are provided with binding-posts for the purpose of connecting in the known and unknown resistances.

**467. How is the slide-wire bridge connected for testing purposes?**

The strips *A* and *D* are connected to a battery *b*, and a low-resistance galvanometer *g* is connected between the strip *C* and the slider. In the diagram, $b'$ and $g'$ represent keys, the former for opening and closing the battery circuit, and the latter for opening and closing the galvanometer circuit; *x* represents the resistance to be measured, and *r* a known resistance of the same general order as *x*, that is, if *x* is approximately 2 ohms resistance, *r* should be about that value.

**468. Describe the method of operating the bridge.**

Close the keys $b'$ and $g'$, and see if the galvanometer needle is deflected; if so, this denotes an unbalanced condition in the resistances of the bridge. Move the slider *B* along the wire—thereby adding the resistance of the wire to one resistance and subtracting it from the other—until a balance is obtained, that is, until the points *B* and *C* are at the same potential. When this occurs, there will, of course, be no deflection in the galvanometer upon closing the keys $b'$ and $g'$. The battery key should be closed a few seconds before closing the key in the galvanometer circuit, so that the current may become steady before the galvanometer is put into circuit.

Then, as the resistance of the slide wire is uniform, the value of *x*, the unknown resistance, can be obtained at once from that of the known resistance and the scale reading, by means of the formula

$$x = \frac{a}{d} \times r.$$

In this formula, $a$ and $d$ are the distances from the pointer on the slider to the ends of the scale, respectively, and $r$ is the known resistance in ohms. Strictly speaking, $a$ and $d$ in the formula represent the resistances of the two divisions of the wire, but as the resistance of the wire is uniform, the ratio of the resistances equals the ratio of the lengths.

**469. Give an example of the application of the formula in Answer 468.**

Suppose that with a standard 1-ohm resistance at $r$ a balance is obtained when the slide is in such a position that $a = 650$ and $d = 350$. Substituting in the formula the values of $a$, $d$ and $r$,

$$x = \frac{650}{350} \times 1 = 1.857 \text{ ohms.}$$

The value of the unknown resistance is, therefore, 1.857 ohms.

**470. Are any special precautions necessary to obtain very accurate results with the slide-wire bridge?**

Yes; in order to obtain the most accurate results it is necessary to correct, in part, for contact resistance at the ends of the German silver wire. To accomplish this the known and unknown resistance should be interchanged, and a second measurement taken. Taking the average of the two values found for $x$ will tend to neutralize any error due to the above cause.

The resistances $x$ and $r$ should also be placed so that the current flowing through them will not affect the galvanometer inductively. This may be tested for by disconnecting the galvanometer leads and making and breaking the current through the rest of the apparatus; if there is no deflection of the galvanometer needle under these conditions, there is no inductive effect.

In order to secure good contacts, the wires should be scraped before a connection is made, and the binding-posts should be occasionally cleaned.

**471. Describe the construction of the galvanometer referred to in connection with the slide-wire bridge.**

One of the common forms of galvanometers used is shown in Fig. 140. It is called a D'Arsonval reflecting galvanometer

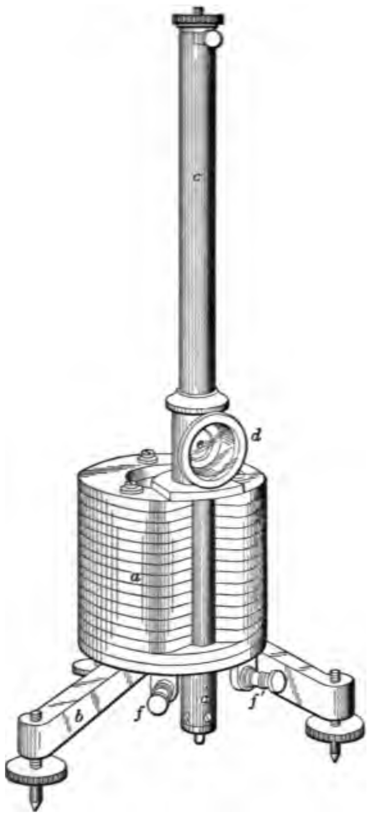



Fig. 140.—D'Arsonval Galvanometer.

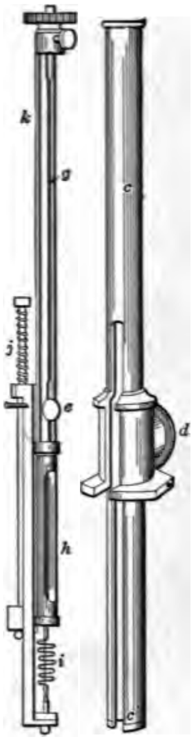



Fig. 140A.—Details of D'Arsonval Galvanometer.

and comprises a permanent magnet *a*, which is made up of fourteen smaller magnets bolted together, one on top of the other, their like poles being adjacent. The whole is mounted on a tripod stand *b*, provided with leveling screws; *c c'* is a hollow brass tube, in which the movable part is suspended;

*d* is an opening in the tube, covered with glass, through which the mirror *e* attached to the movable part can be seen. This tube is bolted to the magnets *a*. The binding-posts are shown at *f* and *f'*.

Fig. 140-A shows the movable part and the method of suspending it. A coil of wire at *h*, consisting of a number of turns of phosphor-bronze wire, is suspended from the top of a semi-circular brass tube *k* by the phosphor-bronze wire *g*. The coil is held at the bottom by the phosphor-bronze spring *i*. Current comes in through the spring *i*, passes through the coil to *g*, and thence out by the semi-circular tube *k*. At *j* is shown a spring which serves to clamp the coil and hold it tight, so as to prevent injury when the instrument is not in use. The mirror is shown at *e*, and the brass tube inclosing the movable part is shown at *c c'*; the latter is simply a back view of *c c'* in Fig. 140.

**472. Explain the principle upon which the D'Arsonval galvanometer operates.**

If a current be passed through a wire coil suspended free to swing in a magnetic field, the coil will rotate through a certain angle, the magnitude of which depends upon the strength of the magnetic field, the number of turns in the coil and the strength of the current passing through it. The strength of the field and the number of turns in the coil being constant, the magnitude of the angle through which the coil is deflected is a measure of the current passing through it.

**473. How is the angle of deflection ascertained?**

In order that the deflections of the galvanometer coil may be accurately observed, a telescope and scale are necessary. These are mounted with respect to the galvanometer mirror as shown in the diagrammatic plan, Fig. 141, where *m* is the mirror, *d* the telescope and *s* a scale which is graduated by vertical lines about 1/16 of an inch apart. The graduations are numbered from zero up, the zero point being at

the middle of the scale and the numbers increasing regularly on either side toward the ends.

When the mirror is not deflected it occupies the position shown, and the telescope, being mounted directly above the center of the scale, as shown in Fig. 142, must be inclined

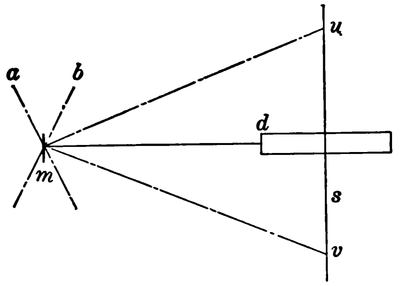



Fig. 141.—Diagram of Galvanometer Mirror, Telescope and Scale.

slightly downward so that the reflected center line of the scale will be seen through the telescope in line with a fine wire stretched vertically across its center. If the mirror be deflected to the position *a* by a passage of current through the galvanometer coils, the reflected line of the scale at *u* will coincide with the center cross-wire of the telescope, while if the mirror be deflected to the position *b*, the reflected line of the scale at *v* will coincide with the center cross-wire. If the center cross-wire of the telescope coincides with the zero of the scale when no current is flowing, then when current is flowing, the reflected line of the scale as seen in line with the center cross-wire of the telescope is a measure of the current producing the deflection.

**474. What precautions should be observed in mounting the galvanometer?**

The galvanometer must rest on a support unaffected by vibrations; the scale must likewise have a stable support, but it need not be as rigid as that provided for the galvanometer. Owing to the movable coil in the D'Arsonval galvanometer

being deflected only by a current passing through it and not by fluctuations in a magnetic field in which it may be placed, the galvanometer can be used in the vicinity of dynamos and motors without being affected by them. The coil, being held top and bottom, is not as sensitive to mechanical jars as in some other types of galvanometers.

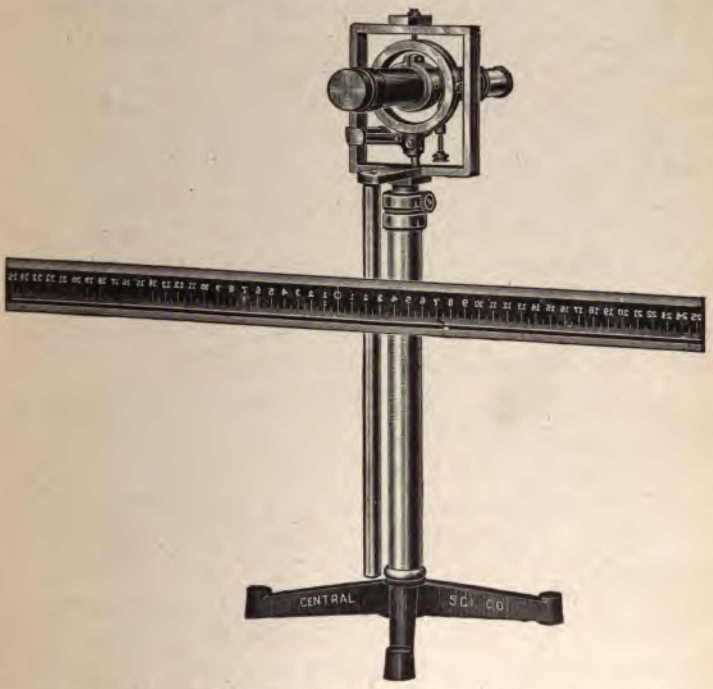



Fig. 142.—Telescope, Stand and Scale used with Reflecting Galvanometer.

The instrument when placed in its desired position should be turned until the plane of its coil is in the North and South magnetic meridian. A compass placed beside the galvanometer will determine this position. The glass-covered opening *d* should be turned squarely to the front, and the instrument leveled by using spirit levels. The object in level-

ing the galvanometer is not to get the instrument vertical, but to allow the needle to swing freely.

**475. What is the proper way to mount the scale?**

The scale should be placed three feet from the mirror and should also be set in line with the North and South magnetic meridian.

The zero point of the scale, the center of the mirror and the wire in the telescope must all be in the same vertical plane. The telescope or scale should be raised or lowered until the reflection from the galvanometer mirror falls so as to be neither too high nor too low. If it be necessary to turn the mirror slightly in order that the reflected center line of the scale coincides with the center cross-wire in the telescope, this may be done by turning the suspension nut at the top of the galvanometer a trifle to the right or left. The telescope should finally be focused so that the scale and cross-wire are clear and distinct, after which the galvanometer is ready to be connected in circuit and utilized.

**476. Is any adjustment of the galvanometer necessary?**

Yes; it is sometimes necessary to vary the sensibility of the galvanometer for different currents so that the deflections will be of the proper magnitude to be recorded on the scale, and for this purpose shunts are employed. Galvanometer shunts are made up in various ways, but the usual arrangement is to have three coils: one a resistance of 1/9, one a resistance of 1/99 and one a resistance of 1/999 that of the galvanometer. If 1/10 of the main current must pass through the galvanometer to secure a convenient deflection, the shunt having 1/9 the resistance of the galvanometer is connected across its terminals; for 1/100 of the main current, the 1/99 shunt; and for 1/1000, the 1/999 shunt.

**477. What is the usual method of measuring resistances above two or three ohms?**

For measuring resistance above two or three ohms, the Wheatstone bridge is used.

**478. Explain the principle of the Wheatstone bridge.**

The Wheatstone bridge consists of an arrangement of resistances, represented in Fig. 143, at *a, b, r* and *x;* the first three of these have known values, and the fourth one, *x,* is the resistance to be measured. A battery *E* and a galvanometer *G* are connected as shown, and by adjusting the three

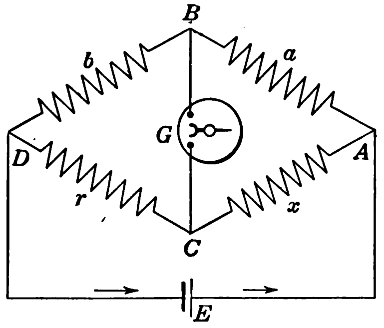



Fig. 143.—Diagram of Wheatstone Bridge.

known resistances so that no current flows through the galvanometer, the value of the unknown resistance can be calculated by simple proportion from the known values of the other resistances.

**479. What conditions must exist in order that there be no current flowing through the galvanometer G, Fig. 143?**

The junction points *B* and *C* must be at the same potential.

**480. Explain in detail what occurs when the junctions B and C are, and are not, at the same potential.**

Current from the battery *E* on arriving at the point *A* will divide and some will travel through the resistance *a* to the point *B,* and the rest will travel through the resistance *x* to the point *C.* If the points *B* and *C* were not connected through the galvanometer, all the current arriving at *B* would pass to the point *D* through the resistance *b,* and all the current arriving at the point *C* would find its way to the point *D* through the resistance *r.* The current, in this case,

would divide in the two branches in inverse ratio to the resistances of the two paths $a + b$ and $x + r$. That is to say, if the resistance of $a + b$ was twice as large as that of $x + r$, twice as much current would flow through the path $x + r$ as in the path $a + b$.

With the galvanometer $G$ connected as shown, another condition prevails. If the points $B$ and $C$ are at the same potential, no current will flow through the galvanometer. If, on the other hand, these two points are of unequal potentials, a current will flow through the galvanometer from the point of higher to the point of lower pressure, causing a deflection of the needle of the galvanometer.

By Ohm's law, the current in any part is equal to the difference of potential divided by the resistance, and when there is no current flowing through the galvanometer, the current in $b$ is equal to that in $a$; hence

$$\frac{\textit{the fall of potential in } a}{\textit{the resistance of } a} = \frac{\textit{the fall of potential in } b}{\textit{the resistance of } b}$$

or

$$\frac{\textit{the fall of potential in } a}{\textit{the fall of potential in } b} = \frac{\textit{the resistance of } a}{\textit{the resistance of } b}$$

Similarly in the other branch, the current in $r$ is the same as in $x$, and hence

$$\frac{\textit{the fall of potential in } x}{\textit{the fall of potential in } r} = \frac{\textit{the resistance of } x}{\textit{the resistance of } r}$$

Since $B$ and $C$ are at the same potential, the fall of potential in $a$ is equal to the fall of potential in $x$, and the fall of potential in $b$ is equal to the fall of potential in $r$. Hence, as the first members of the last two equations are equal, numerator to numerator and denominator to denominator, the second members are therefore equal, that is,

$$\frac{a}{b} = \frac{x}{r}, \text{ or } x = \frac{a}{b} r.$$

So, with the condition of "balance" just mentioned, and

the values of $a$, $b$ and $r$ known, the value of $x$ can be calculated easily.

**481. What precaution is necessary in the arrangement of the parts of the Wheatstone bridge to insure accuracy?**

Greater sensitiveness is secured by having the galvanometer

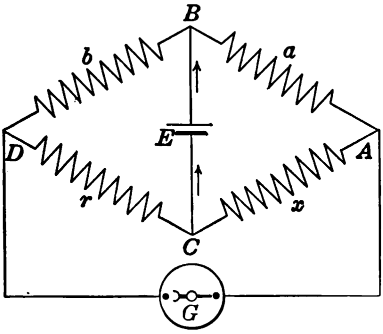



Fig. 144.—Wheatstone Bridge Connections for Maximum Sensitiveness.

connections reach from the junction of the higher two resistances to the junction of the lower two; in other words, by interchanging the positions of the battery and galvanometer so that they are connected as indicated in Fig. 144.

**482. Does this change affect the proportion between the four resistances, given in Answer 480 as being necessary to obtain a measurement?**

No; the proportion remains the same, and $x = \frac{a}{b} r$, as before.

**483. Have the resistances a, b, x and r any special names in connection with the Wheatstone bridge?**

Yes; $a$ and $b$ are known as the "ratio arms"; $x$ is the "unknown resistance arm," and $r$ is the "rheostat arm."

**484. Describe a form of Wheatstone bridge in use.**

A typical portable form of this bridge is shown in Fig. 145. Two rows of resistance coils at $d$ and $d'$ form the rheostat arm, and the row of coils at $e$ constitutes the ratio arms, this

row being divided into two parts for the arm *a* and the arm *b*, respectively.

The resistance coils cannot be seen in Fig. 145; only the brass blocks to which they are connected are visible. The


Fig. 145.—Portable Wheatstone Bridge.

coils are of silk insulated wire wound non-inductively on spools: that is, the wire is first doubled, the closed end is placed on the spool and the wire wound double over it and around the spool. Any electromagnetic action in one half is then neutralized by a similar equal action in the other half, so there is no inductive effect when the circuit is opened or closed.

The box *a* contains, besides the resistance coils, the galvanometer *h*, and the battery. Four terminals from the battery can be seen at *f*, *f'*, *f''* and *f'''*, and connection with the battery is made at the binding posts *m* and *m'* by means of the flexible cords *k* and *k'* and connectors *l* and *l'* attached

to these cords. The binding posts to which the unknown resistance is fastened are denoted by $g$ and $g'$.

**485. Why are four battery terminals used?**

In order to obtain different battery strengths, according to the nature of the test. For measuring very high resistances more voltage is required than for measuring moderate resistances. The use of several cells of battery connected to corresponding terminals enables the operator to grade the test voltage according to the nature of the work.

**486. Show the actual circuits of the apparatus illustrated in Fig. 145.**

Fig. 146 is a plan view of the bridge with all connections indicated. The rheostat arm of the bridge is in two rows

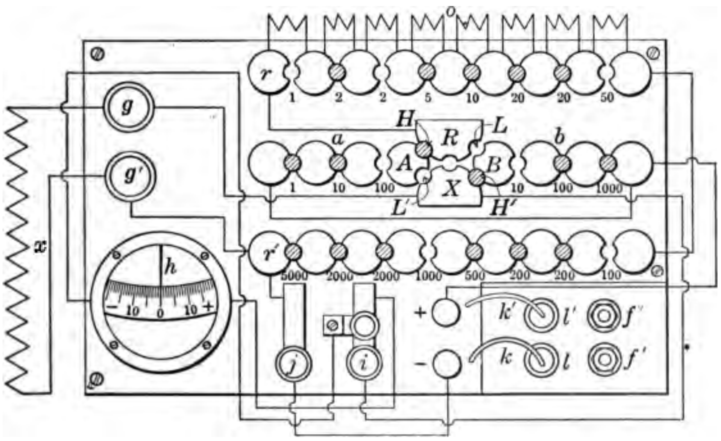



Fig. 146.—Plan View of Portable Wheatstone Bridge.

$r$ and $r'$, each containing eight coils. Those in the row $r$ have resistances of 1, 2, 2, 5, 10, 20, 20 and 50 ohms, respectively, and those in the row $r'$ are of 100, 200, 200, 500, 1000, 2000, 2000 and 5000 ohms resistance. The resistance coils of the first group are represented at $o$. The numbers at the holes into which the short-circuiting plugs are inserted correspond

to the resistance in ohms of the coils connected to the brass blocks. When a plug is withdrawn from a hole, a resistance equal in ohms to the number at the hole is inserted in the rheostat arm, and the total resistance in the rheostat is always equal to the sum of the numbers at the unplugged holes.

The ratio arms are shown at *a* and *b*, the former being made up of three coils, of 1, 10 and 100 ohms respectively; the other arm is composed of three resistance coils of 10, 100 and 1000 ohms, respectively. The two arms are connected together by means of four metal blocks, *A*, *R*, *B* and *X*. By inserting two plugs, one at *H* and the other at *H'*, the two arms *a* and *b* can be connected together. By taking out these two plugs and inserting them in *L* and *L'*, the relative position of the bridge arms can be reversed.

Two keys shown at *j* and *i*, both in Fig. 145 and in Fig. 146, are used, the former to open and close the battery circuit and the latter to open and close the galvanometer circuit. Two of the battery terminals are shown at *f'* and *f''*, the flexible cords at *k* and *k'* and the connectors at *l* and *l'*.

**487. Describe the method of using the Wheatstone bridge.**

The resistance *x* to be measured is connected to the binding-posts *g* and *g'*. Plugs are inserted in *H* and *H'*, and the battery connected by means of the flexible cords *k* and *k'*. Suppose 100 ohms be unplugged in one of the ratio arms, and 10 ohms in the other; also that a certain resistance be inserted in the rheostat arm.

If, now, upon pressing both the battery and galvanometer keys *j* and *i*, the galvanometer needle *h* is deflected toward the side marked +, there is too much resistance in the rheostat, and plugs must be inserted until, upon closing the keys *j* and *i*, the needle *h* remains at 0. The bridge is then said to be balanced. When this condition is obtained, the sum of all the resistances unplugged in the rheostat arm multiplied by the ratio of the sum of the resistances un-

plugged in the *a* side of the ratio arm to that unplugged in the *b* side, equals the unknown resistance *x*.

If on first closing the keys *j* and *i*, the needle *h* swings toward the side marked —, it indicates that there is not enough resistance in the rheostat arm, and that more coils must be unplugged to get a balance.

**488. What would be the unknown resistance x, if a balance was obtained with the Wheatstone bridge in the exact condition shown in Fig. 146?**

The shaded circles represent the holes into which plugs have been inserted, and the coils therefore cut out, while the circles shown white indicate the coils that are in circuit.

It is evident, then, that $a = 100$, $b = 10$, while $r = 1 + 2 + 50 + 100 + 1000 = 1153$ ohms. Therefore, according to the formula

$$x = \frac{a}{b}r, \ x = \frac{100}{10} \times 1153 = 11{,}530 \text{ ohms.}$$

**489. What would have been the resistance x, if the conditions remained the same, with the exception that the plugs were taken out of H and H′, and inserted in L and L′?**

The positions of the ratio arms would be reversed, so that the values would be as follows: $a = 10$, $b = 100$ and $r = 1153$. Substituting these values in the formula, the result would be 115.3 ohms.

**490. What are the limiting values of x possible to measure on the Wheatstone bridge in Fig. 146?**

The lowest value is $x = \frac{1}{1000} \times 1 = 0.001$ ohm.

The highest value is $x = \frac{1000}{1} \times 11{,}110 = 11{,}100{,}000$ ohms.

**491. Mention any precautions that should be observed in using the Wheatstone bridge.**

The ratio of *a* to *b* or *b* to *a* should not be greater than 10 to 1 in very accurate measurements of high resistances,

as any error due to contact resistances, etc., is multiplied according to the ratio used. In any case the most reliable results are obtained when the four resistances $a$, $b$, $r$ and $x$ are of nearly the same value, that is, when no one of them is more than ten times the value of any other.

The brass plugs must be twisted in firmly to avoid what is called plug resistance. At the end of the test, however, the plugs should be loosened to relieve the strain on the top of the box.

The battery circuit should be closed about 10 seconds before the galvanometer circuit, so as to allow the current to become steady.

In case an exact balance cannot be obtained, the results secured for deflections of the galvanometer needle in opposite directions should be interpolated.

**492. Explain what is meant by interpolating the results obtained on a Wheatstone bridge.**

It will not generally be possible to secure exact balance, that is, absence of deflection in the galvanometer, but two values of $r$ may be found differing by 1 ohm, which will cause the galvanometer needle to give deflections in opposite directions. The correct value of $r$ lies between. Hence, at the highest ratio of $\frac{a}{b}$, values of these deflections in opposite directions should be found. Thus suppose with a ratio of $\frac{a}{b}$ equal to 1/1000, 10,042 ohms in the rheostat arm give a galvanometer deflection of 3 divisions to the right of the zero mark, while 10,043 ohms in the rheostat arm give a deflection of 2 divisions to the left of the zero mark. A change of 1 ohm, therefore, causes a movement of 5 divisions. Consequently, to cause a movement of 1 division will require 1/5 ohm, and for a movement of 3 divisions 3/5 or 0.6 ohm. Ten thousand and forty-two ohms being too small by a deflection of 3 divisions, 10,042.6 ohms will, by interpolation as this process is called, be the correct resistance $r$ to cause an exact balance.

**493. If change of temperature affects resistances as has previously been stated, is it not necessary in very accurate resistance measurements made by means of the Wheatstone bridge to allow for the effect which the temperature at the time of the measurement has upon the bridge resistances?**

Ordinarily, a change of temperature affects resistance to the extent of about four-tenths of one per cent. per degree Centigrade of change, as was explained in Answer 50. In the Wheatstone bridge, however, the resistance coils are of either German silver or platinoid, or sometimes manganin, these materials being used largely on account of their comparative low temperature coefficients or change in resistance per degree change in temperature.

For example, the temperature coefficient of German silver is only about 0.00044, but unless the temperature at the time the resistance measurements are taken is the same as that at which the resistances of the Wheatstone bridge have been calibrated, which latter temperature is stamped on the bridge, the correction should be made if it be desired to secure extremely accurate results.

The correction, however, need be applied only to the known resistance ***r***, because the resistances $a$ and $b$ being of the same kind of metal the ratio of $a$ to $b$ as used in the formula $x = \frac{a}{b} \times r$ will not be affected by any change in temperature.

**494. Determine very accurately the resistance introduced in the x arm of a Wheatstone bridge composed of German silver resistances if a balance be obtained with a = 1, b = 100 and r = 542, the temperature at which the bridge resistances were calibrated being 19 degrees Centigrade, and the temperature when the balance was secured being 15 degrees Centigrade.**

For $19 - 15$, or 4 degrees, change in temperature there results, according to the temperature coefficient of German silver given in Answer 493, a correction factor of $4 \times 0.00044 = 0.00176$. As the balance was secured at a

lower temperature than that at which the bridge resistances were calibrated, their exact resistance would be less than the figures marked above them on the bridge, because the resistance of a metal decreases with a decrease in temperature; it therefore becomes necessary to multiply the recorded value of the known resistance, or 542 ohms, by 1 — 0.00176, or 0.99824, which gives 541 ohms for *r*. Proceeding as usual to find the unknown resistance from this value of *r*, we have $x = \frac{1}{100} \times 541 = 5.410$ ohms.

**495. What method is used for measuring resistances higher than those which can be ascertained by means of the Wheatstone bridge?**

The direct-deflection method.

**496. Illustrate and describe the direct-deflection method.**

Suppose a battery *B* of many cells be arranged in series, as in Fig. 147, with a delicate high-resistance D'Arsonval

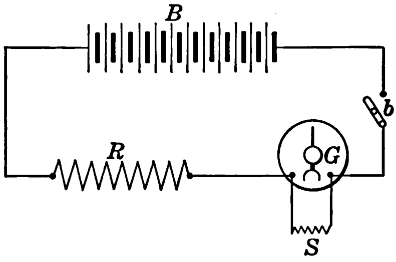



Fig. 147.—Diagram of Direct-Deflection Method for Measuring Resistance.

galvanometer *G*, a high resistance *R* of known value, and a shunt *S* composed of three coils, one having a resistance of 1/9, the second 1/99, and the third 1/999 that of the galvanometer.

Before commencing the test it is necessary to have the number of cells in the battery, and the value of the galvanometer shunt used, such that upon closing the key *b* a scale deflection of convenient extent is given by the gal-

vanometer. Suppose the deflection obtained with the resistance $R$ in circuit be called $D$.

If, then, in place of the resistance $R$, the unknown high resistance $X$ be introduced in circuit, a deflection of a certain number of scale divisions which may be represented by $D_x$ will be given by the galvanometer upon closing the key $b$. The value of the resistance $X$ may then be found from the formula

$$X = R\frac{D}{D_x}.$$

**497. What would be the resistance of X by the method described in Answer 496, if the galvanometer gave a deflection of 100 scale divisions with a known resistance of 1,000,000 ohms, and a deflection of 25 divisions with the unknown resistance in circuit?**

Substituting for $R$, $D$, and $D_x$, their respective values of 1,000,000, 100 and 25 in the formula $X = R\frac{D}{D_x}$ there results $X = 1{,}000{,}000 \times \frac{100}{25} = 4{,}000{,}000$ ohms. The value of the unknown resistance is therefore 4 megohms.

**498. For what class of work is the direct-deflection method of measuring resistances suitable?**

For the measurement of resistances greater than one megohm (1,000,000 ohms). The insulation on wires and cables, and insulators for low-potential work, are usually tested by this method.

**499. When insulators are tested by the direct-deflection method, how are they arranged?**

They are usually placed, inverted, in a box lined with zinc, as shown at $z$, Fig. 148. The box is partly filled with water, and water is also poured into the insulators $i$, $i$, in sufficient quantities to reach within an inch of the rims. The rims should be dry, and the test should not be made on a damp day. One pole of the battery $B$ is connected with the zinc lining of the box and the other pole is connected to one

terminal of the galvanometer *G*, connection being made on the shunt box *S*. The other terminal of the galvanometer is then connected to one end of an insulated wire *a*, this connection being also made on the shunt box S.

There should now be no deflection in the galvanometer if the wire *a* is perfectly insulated. To insure this the wire

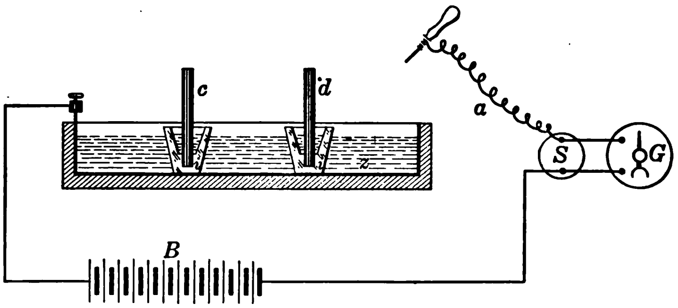



Fig. 148.—Method of Testing the Insulation Resistance of Insulators.

had better not come in contact with the ground or wall of the room. It should be an "air line" as nearly as possible, and supported, if necessary, only by wood or rubber. The insulation of the testing wire being thus rendered certain, and the galvanometer shunted with the 1/999 shunt, the free end of this wire, supported by a wooden holder, should be touched to the metal pins *c* and *d* inserted in the sockets of the insulators under test. In cases where there is no reading, the insulator has stood the test. Such cases should then be tried with the 1/99 shunt; then, if this test causes no deflection, with the 1/9 shunt, and finally, without any shunt whatever.

**500. Is not the direct-deflection method suitable for testing insulators intended for high-potential work?**

No; because insulation for high potentials should be tested not so much for simple resistance as for its ability to withstand high potentials; again, the resistance when subjected to a low potential may be quite different from that under a high

potential on account of the electrostatic attraction between the particles, bringing them closer together. In testing such insulators at the factory, it is common to subject all parts to a difference of potential several times that which they are to stand in use.

**501. When the insulation resistance of wire is tested by the direct-deflection method, what is the course of procedure?**

The insulated wire is first immersed in a tank of water for a period of forty-eight hours, in order to allow the insulation to become thoroughly saturated, after which connections are made with the wire and the water in the tank, as shown in Fig. 149. The positive terminal of the battery, *B*, is connected to the contact blade *m* of the battery-reversing key shown at *m l*. The negative terminal of the battery is

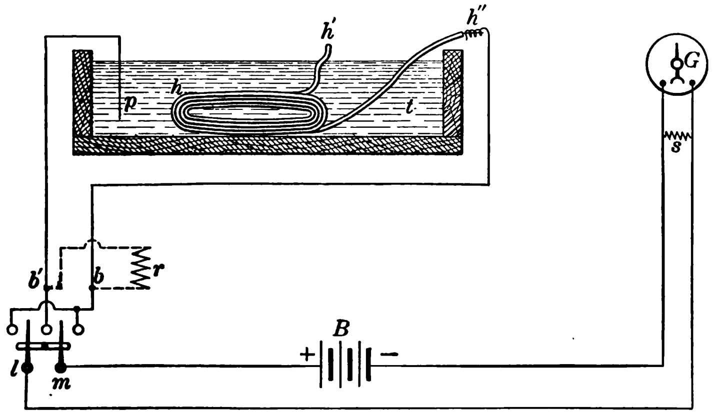



Fig. 149.—Method of Testing the Insulation Resistance of Wire.

connected to one of the galvanometer terminals, and the other terminal of the galvanometer is connected to the contact blade *l*, of the key. A known resistance *r* has its terminals connected to *b'* and *b* of the key. This connection is shown with dotted lines. The shunt for regulating the sensibility of the galvanometer is indicated by *s*.

The circuit runs from the positive terminal of the battery to *m*, and when the key *m l* is thrown to the right, the circuit continues to *b*, through the resistance *r*, back to the binding post *b*′, and thence to the binding post *l*. The circuit then continues on through the galvanometer *G* and back to the negative terminal of the battery. On completing this circuit a certain deflection will be obtained at the galvanometer, and its amount should be recorded.

The coil to be tested is shown at *h*, and is immersed in a tank *t*, filled with water. The terminals *h*′and *h*″ are brought over the edge of the tank. The terminal *h*″ is cleaned of insulation and connected to the binding post *b*. The end *h*′ is allowed to hang free, but out of water. From the binding post *b*′ a wire is run into the water in the tank, the end *p* of this wire being cleaned so as to obtain a good electrical contact with the water. The terminals of the known resistance *r* are then disconnected from the circuit.

The key is thrown to the right,* closing the circuit from the positive side of the battery *B* to *m* and to *b* as before; to the wire terminal *h*″, through the insulation of the coil *h*, through the water to *p*, thence back to *b*′, through *l* to and through the galvanometer *G* and back to the negative terminal of the battery. A deflection is obtained in the galvanometer *G* on completing this circuit. By comparing this deflection with the one obtained through the resistance *r*, the insulation of the coil *h* can be calculated as described in Answer 496.

By reversing the key *m l*, Fig. 149, the circuit will run from the positive terminal of the battery *B* to *b*′, thence to *p*, through the insulation to *b*, to *l*, through the galvanometer *G* and back to the negative terminal of the battery. The first position of the key connects the positive terminal of the battery to wire, and the negative terminal to the water; the second position connects the negative terminal of the battery to wire and the positive side to water. The deflections result-

* The key is actually made to be depressed instead of moved sidewise, and, when released, the blades rise. Depressing the actual key produces the same results as throwing the diagrammatic key to the right.

ing will probably be the same in both cases, but if not, their average value should be used.

**502. When the insulation resistance of cables is tested by the direct-deflection method, what is the course of procedure?**

Cables are tested in the same manner as wire, each conductor being tested separately. When the cable is lead-covered, however, it is not immersed in water. All conductors except the one for test are bound together at one end and then to the lead sheath, with copper wire. At the other end of the cable the conductors are left separate from each other. The conductor undergoing test is connected to the test wire, and when the test on it is finished, the next wire is taken, and so on.

In Fig. 150, *a* is the lead sheath of a cable and *w* its interior insulation. At *h* and *h'* are the conductors, each with its indi-

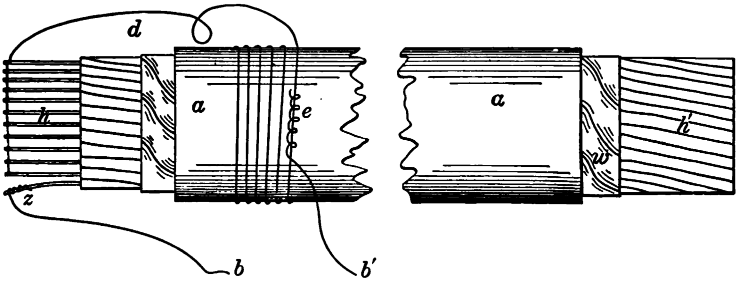



Fig. 150.—Connections for Testing the Insulation Resistance of Cable.

vidual covering of insulation. At *h* the ends are bared and bound together with the wire *d*, which is then bound around the sheath *a*. The conductor being tested is connected at *z* to the test wire *b*, which leads to the binding post *b*, Fig. 149. At *e* a conductor *b'* is connected to the binding wire and leads to the binding post *b'*, Fig. 149. The test circuit is thus complete from *b* to the conductor at *z*, thence through the insulation, to the lead sheath, to the binding wire and back to *b'*. The conductors at the end *h'* of the cable, being sep-

arate, prevent short circuits, that is, electrical contacts between themselves throughout the changes made in the test.

**503. If the insulation resistance of a certain length of wire or cable be determined by measurement, can its insulation resistance per mile be calculated from this?**

Yes, if $l$ = length in feet of the wire or cable tested; $r$ = its insulation resistance as determined by measurement; and $R$ = its insulation resistance per mile; then

$$R = \frac{lr}{5280}.$$

**504. What is the insulation resistance per mile of a cable 2640 feet long if its insulation resistance measures 1200 megohms?**

Substituting for $l$ and $r$ their respective values in the formula

$$R = \frac{lr}{5280},$$

there results $R = \dfrac{2640 \times 1200}{5280} = 600$ megohms;

this is, the insulation resistance per mile.

**505. Is there any other method of testing for resistance than has previously been described?**

A magneto testing set provides a method for ascertaining it approximately.

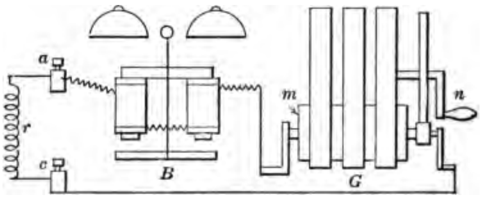



Fig. 151.—Magneto Testing Set.

**506. What is a magneto testing set?**

The set comprises a small hand-operated alternating-current generator $G$, Fig. 151, in series with a bell $B$ which is designed to operate on alternating current. If the resist-

ance *r* to be tested is connected to the terminals *a* and *c* of the set, and the armature *m* of the generator is revolved by the crank *n*, an alternating electromotive force is generated which sends current through the circuit and rings the bell if the resistance of the circuit is not too great.

**507. Explain how the ringing of the bell of a magneto set determines the approximate value of a resistance connected across its terminals.**

The loudness of the ringing indicates roughly the current flowing through the circuit. If one knows the greatest resistance through which his magneto will ring, the loudness of the ringing is a rough indication of the resistance of the circuit being tested. When the bell rings almost as strongly as when the magneto is short-circuited on itself, it shows that the circuit is of low resistance. When the bell rings only feebly, it shows that the resistance is high. If the bell does not ring at all, it indicates that the resistance of the circuit is higher than the range of the magneto; in this case, however, one should test the magneto itself to see if it will ring when its own terminals are connected directly together.

If the resistance is so high that not enough current will pass to ring the bell, one can test the continuity of the circuit by disconnecting one of the wires from a terminal and bridging the gap between them with the fingers of one hand, moistened if necessary. If, then, the magneto be turned fast so as to raise its voltage as much as possible, and the circuit is continuous, a slight shock will be felt through the fingers.

**508. Are there any other methods in common use for measuring resistances accurately?**

There is one other method very often employed for measuring comparatively low resistances. It is called the fall of potential or drop method and is based on Ohm's law. If the fall of potential or the pressure in volts across a certain resistance, and the current in amperes flowing through it, be both measured simultaneously, the resistance in ohms will

be equal to the volts divided by the amperes. The instrument for measuring the volts is called a voltmeter, and that for measuring the amperes an ammeter; these instruments will be discussed later on. Representing the volts by $E$, the amperes by $I$ and the resistance by $R$, the formula is

$$R = \frac{E}{I}.$$

**509. What is the value of a resistance across which a voltmeter indicates 16 volts while the current passing through it, according to the ammeter, is 4 amperes?**

Substituting for $E$ its value of 16, and for $I$ its value of 4 in the formula, there results $R = \frac{16}{4} = 4$ ohms; this is the value of the resistance.

**510. Are any special precautions necessary in applying the drop method of measuring resistances?**

When the resistance of a highly inductive circuit, as that of an armature of a generator, or the windings of a transformer, is to be measured by the drop method, the voltmeter must be disconnected before opening the main circuit, otherwise the inductive discharge which is in the opposite direction to the main current will cause a reverse deflection and probably bend the pointer of the meter.

## MEASUREMENT OF CAPACITY

**511. How is capacity measured?**

Capacity is measured by the direct-deflection method described in Answer 496, the comparisons in this case being made between the unknown capacity and the known capacity of a standard condenser. The standard condenser has a known capacity $C$, between 1/3 and 1 microfarad, and is charged by means of a battery for a certain time, say 30 seconds, and then discharged through a ballistic galvanometer. Represent by $a$ the first deflection produced. A condenser of unknown capacity $C_1$ is then charged with the same

battery for the same length of time. It is discharged through the same galvanometer and a second deflection $a_1$ is obtained. The value of the unknown capacity may then be found from the formula $C_1 = C \frac{a_1}{a}$.

**512. Show the connections and describe the method of procedure in testing capacity by the direct-deflection method.**

Referring to Fig. 152, the condenser $C$ will become charged when the lever $h\,r$ of the discharge key is depressed against

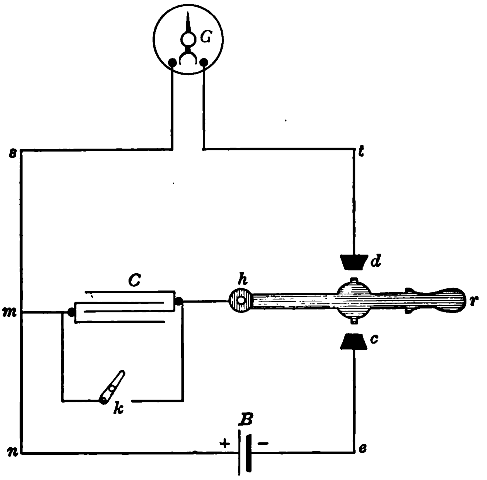



Fig. 152.—Diagram of Apparatus and Connections for Direct-Deflection Method of Measuring Capacity.

the lower stop $c$, for the right-hand pole of the condenser will then receive a negative charge from the battery $B$ by the connection $h\,c\,e\,B$, and the left-hand pole of the condenser will receive a positive charge by the connection $m\,n\,B$. The key being at this charging position, the galvanometer $G$ is set at zero, and when the observer is ready to take a reading, the discharge should be caused by pressing the lever $hr$ against the upper stop $d$. When this is done, the poles of the condenser $C$ are placed in metallic communication by the

circuit $m\ s\ G\ t\ d\ h$, and the sudden rush of electricity through the galvanometer causes the kick, or deflection of its pointer, which has to be noted. While the galvanometer is returning to rest, the condenser should be short-circuited by the key $k$ in order to get rid of any residual charge that may remain. Before again depressing the lever the short-circuit key $k$ should be opened. After the observation of the discharge has been repeated several times for a good average, the condenser $C$ is replaced by the unknown capacity and the process repeated.

**513. Suppose a standard condenser of 1 microfarad capacity gave an average deflection of 60, and the average deflection of the unknown capacity was 54, what would be the value of the unknown capacity?**

Substituting the known values of $C$, $a_1$ and $a$ in the formula $C_1 = C\ \frac{a_1}{a}$, there results $C_1 = 1 \times \frac{54}{60}$, or 0.9 microfarad as the value of the unknown capacity.

**514. What is a ballistic galvanometer?**

A ballistic galvanometer is an instrument adapted for measuring momentary currents, i.e., currents which last only a very short time. It differs from the D'Arsonval galvanometer described in Answer 471, in possessing a heavy needle, made nearly spherical. The needle is made heavy in order that its time of vibration will be large, and is made spherical in order that the air resistance will be a minimum. Thus, as the needle swings slowly around, it adds up, as it were, the varying impulses received during the passage of a momentary current, and eliminates to a certain extent the magnetic and frictional resistances which tend to shorten the deflection.

**515. Illustrate and describe a common form of ballistic galvanometer.**

Fig. 153 shows a modern form of ballistic galvanometer. The coils $c'$ and $c''$, with terminals at $m$, $m'$, $m''$ and $m'''$, are

supported by means of the polished hard-rubber pillars $p'$ and $p''$, corrugated in order to give a large leakage surface. The two coils are graded to give the maximum electromagnetic effect for a given length of wire. They are joined by means of flexible insulated-wire connectors in series, multiple, differentially or singly, according to the resistance required to produce a readable deflection in the measurements being made. The coils are hinged, and can be swung open as in Fig. 153 so that the suspension system $e$ may be easily in-

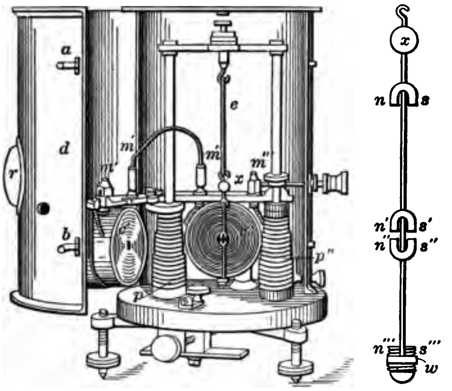


Fig. 153.—Ballistic Galvanometer for Measuring Transient Currents.

spected. By means of the clasps $a$ and $b$ the part $d$ can be securely closed, thus causing the coils $c'$ and $c''$ to inclose the suspension system. When the part $d$ is closed, a glass window, the frame of which can be seen at $r$, permits the mirror $x$ on the suspension system to be plainly seen.

The suspension system shown enlarged at the right of Fig. 153, consists of the mirror $x$ and four bell magnets $n\,s$ and $n'\,s'$, $n''\,s''$ and $n'''\,s'''$, the upper and lower magnets $n\,s$ and $n'''\,s'''$ forming one set, and the central pair $n'\,s'$ and $n''\,s''$ the other. The outer magnets, being the stronger, control the system. The lower magnet has a screw thread cut on it, upon which moves a soft-iron ring $w$. Screwing this ring toward the poles of the magnet makes the system more nearly

neutral to the earth's magnetic force; this gives a means of varying the sensibility of the galvanometer through a wide range.

**516. Mention a common case where measurements of capacity are necessary.**

All lead-covered cables should be tested for capacity between the conductors and the lead sheath.

**517. How are the connections made in determining the capacity of a lead-covered cable?**

The conductors are left open at one end, as at $h'$, Fig. 150, and those at the other end $h$ are bound together and to the sheath. The sheath is connected to $h$, Fig. 152, and the conductor to be tested is connected to the positive side of the battery $B$, and also to one terminal of the galvanometer $G$. The other terminal of the galvanometer is joined to the stop $d$ and the negative side of the battery to the stop $c$. The deflection produced is that of the unknown capacity, the method of procedure being the same as that described in Answer 512.

**518. If the capacity of a certain length of cable be determined by measurement, can its capacity per mile be calculated from this?**

Yes; if $l =$ length in feet of the cable tested; $c =$ its capacity in microfarads as determined by measurement, and $C =$ its capacity in microfarads per mile, then

$$C = \frac{5280\, c}{l}.$$

**519. What is the capacity per mile of a cable whose capacity measures 0.014 microfarad for 750 feet of its length?**

Substituting for $c$ and $l$ their respective values in the formula

$$C = \frac{5280\, c}{l},$$

there results

$$C = \frac{5280 \times 0.014}{750},$$

or 0.099 microfarad for the capacity per mile.

## MEASUREMENT OF INDUCTANCE

**520. Describe a method of measuring inductance.**

Inductance may be measured with a Wheatstone bridge, condenser, and a variable non-inductive resistance connected as in Fig. 154. In the diagram, $a$ and $b$ are the ratio arms of the bridge, in each of which is introduced the same amount of resistance. Connected in the $x$-arm of the bridge is the inductive resistance $L$, the inductance of which is to be measured, in series with a non-inductive resistance $R$, and shunted around these two resistances is a condenser $c$. The resistance

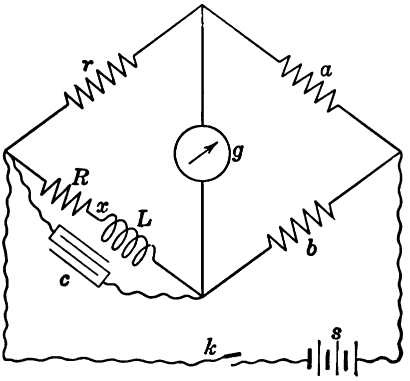



Fig. 154.—Connections for Measuring Inductance with Wheatstone Bridge.

$R$ is used merely for the purpose of enabling a condenser $c$ of practicable size to be employed. The variable-resistance arm of the bridge is denoted by $r$, the battery by $s$, the battery key by $k$, and the galvanometer, which should be of the reflecting type, by $g$.

The test is conducted by varying the resistance in $r$, and if necessary the values of $R$ and $c$, until no deflection is given by the galvanometer when the battery circuit is opened. Then, by substituting the values of the capacity of the condenser $c$ in microfarads, and of the resistance $R$ and $r$ in ohms, in the formula

$$L = c\ (R + r)^2,$$

the value of the inductance $L$ in henrys can be at once obtained.

**521. If the galvanometer in Fig. 154 gives no deflection upon opening the key k when there is 1 ohm unplugged in each of the ratio arms, 1 ohm in the variable-resistance arm, 1 ohm of non-inductive resistance in the x-arm, and the condenser used has a capacity of 0.3 microfarad, what is the value of the inductance L?**

Substituting 0.3 for $c$, 1 for $R$, and 1 for $r$ in the formula $L = c\ (R + r)^2$, there results $L = 0.3\ (1 + 1)^2$, or 1.2 henrys for the value of the inductance.

## DIRECT-CURRENT PORTABLE VOLTMETERS

**522. Are all voltmeters portable?**

No; voltmeters, or instruments for measuring the electrical pressure or voltage of a circuit, or the drop in pressure across a resistance, are not always portable; neither do all of them operate upon the same principle. The term "portable" signifies that the instrument is constructed so that it can easily be carried from place to place, in contradistinction to "station" voltmeters, which are constructed to be used permanently in one place, as on a switchboard in a station.

**523. Show a typical form of direct-current portable voltmeter.**

Fig. 155 shows such an instrument. This voltmeter is designed to measure direct-current pressures up to 150 volts. Two scales $m$ and $n$ are provided, the former graduated with practically equal subdivisions from 0 to 150 volts and the latter from 0 to 15 volts. Pressures up to 15 volts can be read on the low scale with greater accuracy than if read on the high scale, for the reason that the unit divisions are spaced further apart. Pressures above 15 volts must, of course, be read on the high scale. In order that either scale may be used at will, three binding posts $a$, $b$ and $d$ are provided. When the binding posts $a$ and $d$ are used to connect

the instrument in circuit, the low-reading scale will be in use; the binding posts $b$ and $d$ correspond to the high-reading scale. The circuit through the voltmeter is not closed, and consequently there is no deflection of the pointer $p$ over the


Fig. 155.—Portable Direct-Current Voltmeter.

scale, until the button or key $k$ is pressed down. The instrument is direct-reading; that is, the scale markings represent the exact values being measured.

**524. Show the working parts of this voltmeter and describe the principle upon which they operate.**

A diagram of the working parts is shown in Fig. 156. In a two-scale voltmeter there are two separate resistance coils $a'$ and $b'$, one for each scale. Each of these coils is wound with the same size wire, non-inductively; that is, the wire of each coil is wound back on itself as described in Answer 484 for the resistance coils in the Wheatstone bridge. The wire on coil $b'$, which is used for the 150-volt scale, is nearly ten times the length of that on coil $a'$ for the 15-volt scale. One terminal from each coil is connected to the binding posts $a$ and $b$ respectively, and the remaining two terminals are joined together and electrically connected to $c$, a fine copper-wire coil which is free to turn about a vertical axis. A perspective view of this part of the meter is shown in Fig. 157, with front broken away to make clear the construction. The

other end of the coil *c* is electrically connected to binding post *d* through the key *k*. Within the coil *c* is permanently mounted a cylindrical piece of soft iron *s*, which acts as a core, thereby strengthening the magnetic circuit of the permanent horseshoe magnet *N S*. The coil *c* is wound upon a light frame of copper which serves both as a support for the wire and as a magnetic damper to prevent extra vibrations.

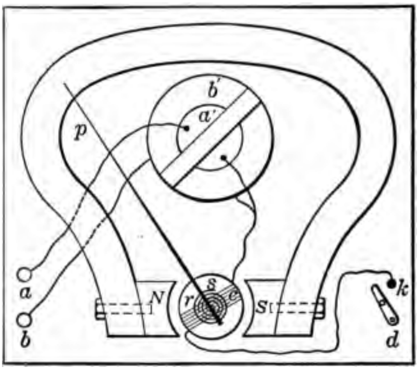



Fig. 156.—Interior Connections of Portable Direct-Current Voltmeter in Fig. 155.

The pointer *p* is mounted on top of coil *c*. When no current is passing through the coil, the pointer is at the left as shown, over the zero mark on the scale. When current passes through the coil in the proper direction, a north pole is produced at the further side of the coil, and a south pole at the nearer side. The repulsion between the like poles of the coil and permanent magnet, and the attraction of the unlike poles, cause the coil to turn so that the pointer is carried over the scale. The position of the pointer thus depends upon the magnetic effect produced by the coil, and this in turn is proportional to the strength of the current passing through it; as the current is proportional to the voltage applied to the binding posts of the meter, the internal resistance of the meter being constant, the position of the pointer is proportional to the voltage applied.

Two flat spiral springs *r*, etc., one fastened to the top, and the other to the bottom of coil *c*, exert a force in opposition to that produced by the current in the coil; consequently, when no current flows through the instrument the force of the springs brings the pointer back to the zero point, which, in this class of instruments, is at the beginning of the scale. These springs also serve to convey the current into and out

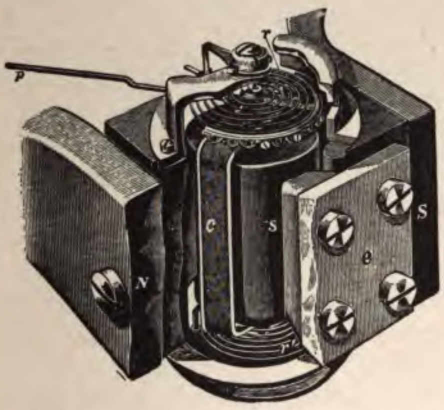



Fig. 157.—Details of Construction in Direct-Current Voltmeter.

of the movable coil. A brass strip *e* screwed to both poles protects the movable coil and springs from injury at the opening of the magnet, but does not intercept the lines of force between the poles because brass is non-magnetic. The moving parts are supported in sapphire jewels, and the pivots are of hardened steel, ground and highly polished, in order to minimize friction and obtain extreme sensitiveness.

**525. What would happen if current were passed through the meter in the wrong direction?**

A south pole would then be formed at the further side of the coil *c*, and a north pole at the nearer side. The attraction of these poles by the poles of the permanent magnet *N S* would cause the coil to move in the opposite direction

to that previously stated, and the pointer would be forced off the scale, at the left.

**526. Does not the movement of the pointer therefore indicate whether the voltmeter is correctly connected in circuit?**

It does. The key *k*, Fig. 155, should be lightly tapped for this test, as otherwise the pointer is liable to be bent by being forced against the side of the case or against the insulated stop provided in some meters. If the deflection is in the wrong direction, the connecting leads should be reversed.

On the meter, Fig. 155, directly below the right-hand binding post is shown a white disk, and if the positive side of the circuit to be tested is known it can be connected to the binding post thus indicated, with the certainty that the pointer will be deflected in the proper direction.

**527. How is the proper resistance for the coils a′ and b′, Fig. 156, determined?**

Each of these coils has a resistance depending upon the full-scale reading which it governs; usually, the coils are wound to make the total resistance of the moving and stationary coils about 100 ohms per volt. The coil $a'$ and the moving coil $c$ therefore have a combined resistance of about $15 \times 100 = 1500$ ohms, and the coils $b'$ and $c$ a resistance of $150 \times 100 = 15{,}000$ ohms.

**528. What are the usual measuring limits in the direct-current portable voltmeters in common use?**

Direct-current portable voltmeters vary from 0.02 volt up to 750 volts rating, the smaller ranges being used for the measurement of very low electromotive forces, such as those developed by the difference in temperature of two metals and by battery cells, or for measuring the voltage across very low resistances, such as armatures of dynamos, heavy cables, etc. The voltmeters in most common use are of 5, 15, 75, 150, 300, 500 and 750 volts range.

**529. How are direct-current pressures in excess of 750 volts measured?**

Direct-current pressures seldom exceed 750 volts, but it is practicable to extend the measuring range of a voltmeter many times by the use of a device called a multiplier. The multiplier is merely a special resistance connected in series with the voltmeter and is often used with low-reading voltmeters to extend their field of usefulness.

**530. Illustrate a multiplier and its principle of operation.**

Fig. 158 shows a multiplier. The perforated cylindrical case contains a resistance connected to the binding posts *m*


Fig. 158.—Multiplier used with Portable Voltmeter.

and *n*, the value of which is some multiple of the resistance of the voltmeter to be used with it; the resistance of the voltmeter circuit is thereby increased a certain whole number of times, and consequently the deflection on the voltmeter scale is decreased in exact proportion. The readings on the voltmeter connected in series with the multiplier have, therefore, to be multiplied by the proportion in which the resistance of the voltmeter circuit has been increased. The perforated

case is used to afford ventilation for the wire within so that its resistance will not be affected by overheating.

**531. What is the voltage of a circuit in which a 150-scale voltmeter having a resistance of 14,812 ohms indicates 115.5 volts when connected with a multiplier of 44,436 ohms resistance?**

According to Answer 530, the multiplying factor would be

$$\frac{14{,}812 + 44{,}436}{14{,}812} = 4.$$

The voltage of the circuit would therefore be $4 \times 115.5 = 462$ volts.

**532. Are any temperature corrections necessary in the readings obtained on the direct-current portable voltmeter, by reason of the change in its internal resistance at different temperatures?**

The temperature correction in the meter illustrated is not over one-quarter of one per cent. between 35 degrees and 105 degrees Fahrenheit, and the instrument gives results correct within one-fifth of one per cent., if carefully used; for commercial work, therefore, the temperature corrections are negligible.

**533. How should a voltmeter be wired in circuit?**

It should be wired across that part of the circuit where the voltage is desired, by small flexible wire leads. If, for example, the voltage of a generator *G*, Fig. 159, be required,

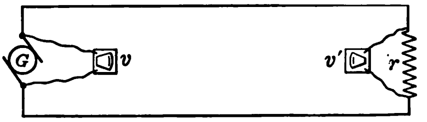



Fig. 159.—Connection of Voltmeter in Circuit.

a voltmeter *v* must be connected to its terminals as shown. If the drop in pressure across a resistance *r* be desired, a voltmeter *v′* must be connected to the ends of the resistance.

The high internal resistance of the voltmeter permits the passage through it of only a very small current; consequently, but a small amount of energy is required to operate it.

**534. What precautions should be observed in connecting up a voltmeter?**

A voltmeter should not be connected to a circuit unless the character of the circuit and its approximate voltage are known. If a voltmeter capable of measuring only 150 volts be connected across a circuit giving 300 volts, and the key be pressed, the resistance coil of the voltmeter, or possibly its fine wire coil, would be burned out. That is, the wire would not carry the current that would then flow through the meter without heating to such an extent as to set fire to its insulation, or at least char it, rendering it unfit for further use.

Voltmeters, and in fact any measuring instrument depending upon the magnetic effect of a current, should not be used in close proximity to dynamos or conductors carrying large currents, because the readings on these instruments are affected by stray magnetic fields, and the steel magnets used in the meters may become permanently changed.

When measuring instruments of any kind are placed upon tables or benches and connected in circuit by means of loose wires or cables, these wires or cables should be securely clamped or fastened to the tables or benches. The instruments will not then be liable to injury if the wires are accidentally caught and pulled.

When carrying instruments or setting them down, they should not be handled roughly. Such treatment dulls the pivots and frequently breaks the jewels.

Care should be taken to prevent either of the connecting leads from touching the case when a voltmeter is in use. The pointers in these instruments are often permanently connected with one side of the circuit and touch the case at the end of their swing. If a lead from the other side of the circuit also touches the case, a short-circuit will be caused.

**535. What precautions should be observed in taking readings on a voltmeter?**

In reading deflections of the pointer on the scales of all instruments, it is generally possible to read to tenths of a division with a fair degree of accuracy. In case a mirror is provided beneath the pointer, advantage should be taken of this feature by sighting the needle so that it covers its reflection in the mirror.

A slight jarring or tapping on the case of the instrument will overcome the friction of the pivot and aid the pointer in coming to rest. A separate key is sometimes used to stop the vibrations of the pointer, especially in the case of alternating-current instruments, as will be explained later.

If the pointer be bent so as to lie more than one-fifth of a division away from the zero mark when no current is flowing, the case of the meter should be unscrewed, taken off, and the end of the pointer bent back to the zero mark. The straightening of the pointer is best accomplished by means of a small pair of pliers.

## DIRECT-CURRENT STATION VOLTMETERS

**536. Wherein does a station voltmeter for measuring direct-current pressures differ from a direct-current portable voltmeter?**

The direct-current station voltmeter is a much larger instrument. Two forms are shown in Figs. 160 and 161, the former being of the illuminated dial type, and the latter of the "edgewise" pattern. The working parts of these instruments operate on the same principle as those of the direct-current portable voltmeters. As but one scale is used, there is but one resistance coil, and as the meter is intended to be permanently connected in circuit a key is not provided.

**537. Describe in detail the meter shown in Fig. 160.**

This meter carries in addition to the pointer *p*, a round index *a*. This latter consists of a circular disk of blackened

aluminum, and its position along the scale can be adjusted from outside of the case by turning the knob *b*. In practice, the knob is turned so that the index *a* is directly below the point of normal voltage. When the pointer *p* reaches the point of normal voltage, the black disk of the normal index *a* appears in the center of the circular opening of the pointer, a narrow ring of white around the disk being visible. By


Fig. 160.—Illuminated Dial Station Voltmeter.

means of this simple arrangement a very small change in the voltage can be seen at a considerable distance from the meter. The dial, or scale, *s*, is of opal glass set in a frame at the back of the instrument. Directly behind the scale, an incandescent lamp and a pair of mirrors are mounted so as to illuminate the scale uniformly from behind, thereby making the figures, lines, pointer and index distinctly visible at a distance from the instrument. Two of the iron brackets used to suspend the meter are shown at *m* and *n*. A dust-proof cast-iron case protects the working parts from injury and shields them from the disturbing influence of external magnetic fields.

**538. What are the features of the edgewise voltmeter in Fig. 161?**

This type is advantageous where it is necessary to mount the measuring instruments very closely together in a limited space. The meter is mounted by cutting out a portion of the switchboard so that the part back of the frame *m* projects through; connections are made to it from the rear. The instrument may be tilted by means of the handle *c* and held

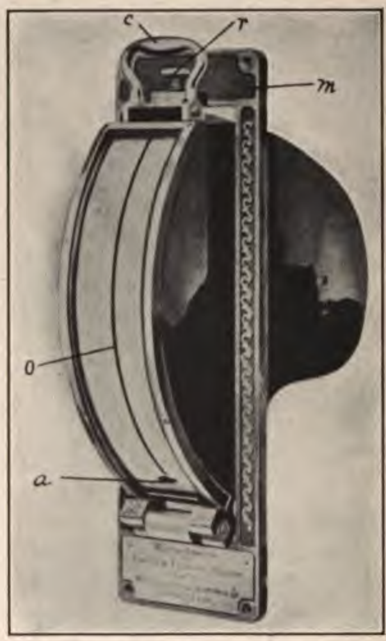



Fig. 161.—Edgewise Type of Direct-Current Station Voltmeter.

in the desired position by means of an insulated thumb screw *r*. This permits the best view of that part of the scale which is most in use and to a certain extent does away with reflections from the curved glass front. The scale of this voltmeter is not illuminated, and a normal-voltage index is not provided. The moving mechanism of the meter is con-

nected to the pointer *a* through the slot *o*. In some meters black dials are used, the figures, scale and pointer being white. Under many conditions of station lighting this arrangement will be found to add considerably to clearness and readability, the principle involved being to illuminate only those parts which are to be observed.

**539. Are multipliers used with station voltmeters?**
Yes; in the same manner as with portable voltmeters.

## DIRECT-CURRENT PORTABLE AMMETERS

**540. Wherein do ammeters differ from voltmeters?**
Ammeters are instruments for measuring the strength of current flowing through a circuit, and they are connected in series with the circuit as at *e*, Fig. 162. If the instrument

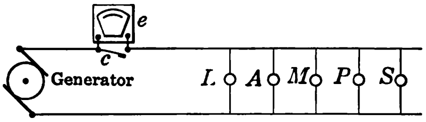



Fig. 162.—Connection of Ammeter in Circuit.

is not to be used continuously, a switch should be wired in as at *c* to short-circuit the ammeter when it is not needed, in order that no appreciable current will pass through the meter, and also in order that the current in the main circuit will not be interrupted in case it becomes necessary to remove the meter. The mechanical construction of direct-current ammeters differs considerably from that of direct-current voltmeters, although the underlying principles of operation are practically the same in both cases.

**541. Show a typical form of direct-current portable ammeter.**
Fig. 163 shows an ammeter complete. Except that the binding posts, *a* and *b*, are larger and there is no key or push-button, the exterior appearance of the meter is similar to that of the direct-current portable voltmeter shown in Fig.

155. The large binding posts are necessary because the entire current of the circuit passes through the meter when

Fig. 163.—Portable Direct-Current Ammeter.

in use, and the short-circuiting switch previously mentioned replaces the key.

**542. What is the interior construction of this type of ammeter?**

Fig. 164 indicates the construction diagrammatically. The permanent horseshoe magnet *N S*, the fine copper-wire coil *c*

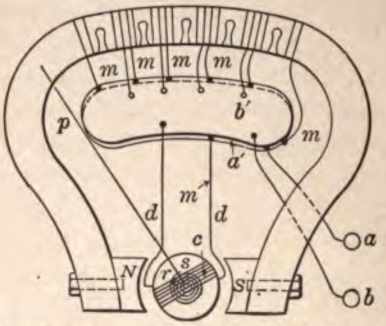



Fig. 164.—Interior Connections of Direct-Current Ammeter.

enclosing the soft-iron core *s*, the spring *r* holding the coil in position, and the pointer *p* attached to the coil, will be recognized at once as being of the same construction and

serving the same purposes as the corresponding parts in the direct-current portable voltmeter described in Answer 524. Here, however, the similarity ends.

The current upon entering the meter at the binding post *a* passes to a copper plate *a′*, and from this plate passes through several resistance coils *m* and the movable coil *c* to the plate *b′*, from which it passes to binding post *b*, and back to the circuit. The proper operation of the instrument largely depends upon the resistance coils *m*, which consist of insulated wires wrapped non-inductively around the permanent magnet *N S* and form the principal conductors of the current. These coils and the movable coil *c* are all connected in parallel between the plates *a′* and *b′*, and the resistances of the coils are so proportioned as to allow the coil *c* to receive the amount of current necessary to cause the proper deflection of the pointer over the scale.

543. **Can this ammeter be kept in circuit continuously?** Not without affecting its accuracy by the heating of the resistance coils, unless the current is relatively weak. If the current is one-half or more of the full range of the instrument it should not be kept in circuit longer than three minutes. As a rule, half a minute is ample time in which to take a reading. If the meter is to be kept in circuit continuously, the current should not exceed one-quarter of the full range of the 300- and 200-scale ammeters, while with the 150-scale ammeter one-third of the full range should be the limit. The 100-scale ammeter may be kept in circuit for five minutes at three-quarters of its full range before its accuracy is impaired more than 1 per cent., and for an indefinite period at one-half range. The 50-scale ammeter may be kept in circuit indefinitely at three-quarters range without exceeding the 1 per cent. limit of inaccuracy, and the 25-, 15-, 5- and 0.75-scale ammeters at full range for an indefinite time.

544. **Are there any precautions besides those already mentioned that should be observed in using ammeters?**

An approximate idea should be had of the current in a

circuit before an ammeter is connected in. The short-circuiting switch should be carefully opened the first time to show whether the current flows through the meter in the proper direction to deflect the pointer over the scale. A slight tapping on the case of the meter will overcome the friction of the pivot and aid the pointer in coming to rest at the proper point. Ammeters should not be used near dynamos, large masses of iron, or conductors carrying large currents, on account of inductive disturbances introducing errors in the readings. The connecting wires or cables should be securely fastened to the table or bench upon which the meter is used. Care should be taken to handle ammeters carefully in order to avoid damage to their pivots or jewels. Ammeters which must be kept in circuit continuously carrying current near their maximum capacity should be connected to the circuit by large wires or cables in order that the heating at the contacts of conductors and binding posts may be kept low.

The meter should be laid approximately horizontal—not vertical nor in an inclined position, because the friction of the bearings is thereby increased and seriously affects the accuracy of the meter. If the meter is to be used for any length of time in one place it is advisable to screw it down. Brass screws should be used; iron screws must not, because they interfere with the deflections of the pointer by distorting the magnetic field. Nails must never be employed to fasten a meter in place, as the necessary hammering would injure the jewels, besides seriously affecting the field of the horseshoe magnet. A meter should never be used in a place hot enough to melt the paraffin insulation on its interior wires. Wiping the glass cover just before taking a reading is liable to electrify the glass and induce a charge in the aluminum pointer, which, being very light, may thus be attracted and cause an error in the readings.

**545. Is there any limit to the range for which an ammeter can be made?**

No; but in practice it is found expedient to use external

" shunts " with ammeters for measuring currents above 200 or 300 amperes.

**546. What is an ammeter shunt and how is it used?**

Fig. 165 shows an ammeter shunt. It consists of a number of metal strips *d*, the ends of which are fitted into grooves in


Fig. 165.—Ammeter Shunt used in Measuring Large Currents.

two brass or copper blocks *r* and *s*. Each of these blocks is provided with two large and one small clamping screw, the former for connecting the shunt in the circuit in which it is desired to measure the current and the latter for connecting the wires *c* leading to the ammeter.. Most of the current passes through the metal strips *d*, but a small part is " shunted " through the meter, and as this small portion varies exactly in proportion to the variations of the main current, the ammeter needle responds in accordance.

**547. Is the ammeter used with shunt the same as the one used alone?**

No; the meter used in connection with shunt is practically a low-reading voltmeter, with a low-resistance moving coil instead of one of high resistance. Its scale is marked in amperes, however, and so laid out that when any certain number of amperes is passing in the main circuit, the needle


Fig. 166.—Illuminated Dial Station Ammeter for Direct Current.

points to that number on the scale, although that current is not actually flowing through the instrument.

**548. Why is the ammeter shunt made up of strips?**

In order to obtain a large radiating surface and thereby prevent heating, which would alter the resistance and make the ammeter readings inaccurate.

**549. Are any special precautions necessary in the use of a shunted ammeter?**

Care must be taken never to allow the full current of a circuit to pass directly through the meter, for it requires less than one-tenth of an ampere to give a full scale deflection.

## DIRECT-CURRENT STATION AMMETERS

**550. Illustrate and describe some common forms of direct-current ammeters for station use.**

Fig. 166 shows a direct-current station ammeter of the illuminated dial type, and Fig. 167 illustrates the edgewise type. Both are designed for use with shunts, and are constructed on the principle described in Answer 547. The

Fig. 167.—Edgewise Type of Direct-Current Station Ammeter.

working parts are entirely enclosed in iron cases to protect them from dust and external magnetic fields.

**551. How are a station ammeter and its shunt connected in circuit at the switchboard?**

Fig. 168 is a diagram of the wiring, in which *a* and *b* represent the connections to the outside circuit; *D*, the dynamo supplying the current; *s*, the ammeter shunt; *R*, the ammeter, and *c*, the switchboard. The shunt should be placed at a greater distance from the ammeter than the diagram indicates; the further away the better on account of its magnetic effect. Connection with the shunt is made by means

of thick copper bars *m* and *n*. The small lead-wires *r* and *v* from the shunt are connected to the binding posts *b′* and *b″* at the back of the meter, where also the socket *x* for the

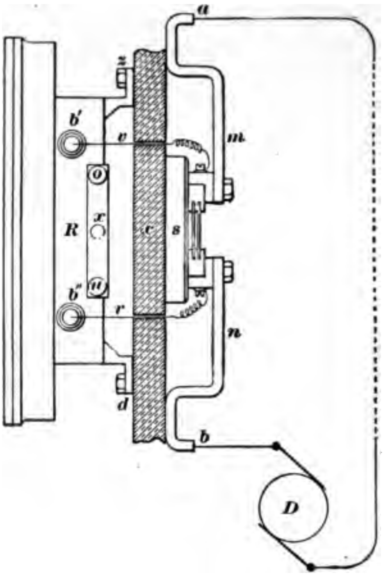



Fig. 168.—Connections for Station Ammeter and Its Shunt on Switchboard.

electric incandescent lamp which illuminates the scale is placed; *u* and *o* are binding posts for the lamp circuit.

## ALTERNATING-CURRENT PORTABLE VOLTMETERS

**552. Can voltages on alternating-current circuits be measured by the direct-current voltmeters previously described?**

They cannot, because the current in the coil would "alternate" rapidly and tend to pull the coil first one way and then the other. The result would be no deflection of the pointer. Alternating-current voltmeters, however, will meas-

ure direct-current voltages as well as alternating-current voltages.

**553. Do all alternating-current portable voltmeters operate upon the same principle?**

No; there are several forms of alternating-current portable voltmeters based on different principles of operation. Among them are moving-coil or " ironless-field " voltmeters, hot-wire voltmeters, and inclined-coil voltmeters.

**554. Explain the principle upon which moving-coil voltmeters operate.**

In this meter there is a fixed coil in two sections, and a movable coil, connected in series. In Fig. 169 *m* and *n* repre-

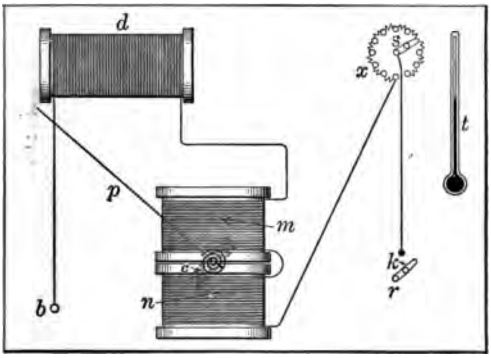



Fig. 169.—**Internal Arrangement of Moving Coil Alternating-Current Voltmeter.**

sent the two sections of the " ironless-field " fixed coil, and *c* denotes the movable coil. The sections of the fixed coil are wound in the same direction on hollow non-magnetic bobbins and serve in place of the permanent magnet used in the direct-current voltmeter. The movable coil is connected in series with the stationary coils and its spindle carries the pointer *p*. The movable parts comprising the coil *c*, the pointer *p*, and the springs attached to the top and bottom of the spindle are of practically the same construction as

those in the direct-current voltmeter described in Answer 524. The high resistance coil of this meter is shown at *d.*

In the "ironless field" meter here described, no matter in which direction the current flows, the attraction or repulsion between the magnetic lines of force generated in the movable coil and those in the field set up by the coils *m* and *n* always tends to deflect the pointer *p* in the same direction. This is due to the fact that the fixed coils and the movable coil are connected in series, and when the current changes direction in one of them it changes direction in all three, thus preserving the same magnetic relation between them. An instrument of this type may be said to operate on the dynamometer principle.

**555. Should any corrections be made in the readings obtained from the voltmeter in Fig. 169 for changes in temperature?**

Yes, but they are applied automatically by means of the rheostat *x,* Fig. 169, which is graduated between 60 and 100 degrees, Fahrenheit. Before taking readings of voltage, the temperature of the surrounding air is noted on the thermometer *t,* and the pointer *s* of the rheostat is turned to the mark corresponding to this temperature. Sufficient resistance is thus cut in or out of the voltmeter circuit to compensate for change in the working resistance of the meter due to change in temperature.

**556. What is the general appearance of a moving-coil voltmeter?**

Fig. 170 shows an exterior view of a two-scale voltmeter of this type. The upper scale is graduated to 150 volts and may be used by connecting to the terminals *a* and *c,* while the lower scale, graduated to 75 volts, may be used by connecting to the terminals *h* and *c.* The high-resistance coil of this meter is divided in two sections and connected as in the case of the two-scale direct-current voltmeter shown in Fig. 156. The key is denoted by *k,* the thermometer by *t,* the compensating rheostat by *x,* and the scale by *s.*

**557. What is the principle upon which hot-wire alternating-current voltmeters operate?**

The hot-wire instrument depends for its operation upon the expansion of a fine wire strip of conducting material, the expansion being due to the heat produced by the passage of the current to be measured. The indications are proportional to the square of the current, because the heating effect varies as the square of the current. Both alternating- and direct-current voltages can be measured with a hot-wire instrument.


Fig. 170.—Portable Alternating-Current Voltmeter of Moving Coil Type.

**558. Illustrate and describe the construction of a hot-wire voltmeter.**

Figs. 171 and 172 show, respectively, interior and exterior views of this instrument. A long piece of platinum silver wire 0.0025 inch in diameter passes up and down the long tube *B*, Fig. 172, over pulleys supported above and below.

One end of the wire is fixed to the small brass block *m*, **Fig. 171.** Thence, the wire is led around one of the two grooved pulleys *b* and *d*, supported by a ring at the bottom of the tube. (In Fig. 171 the bottom of the tube is brought close

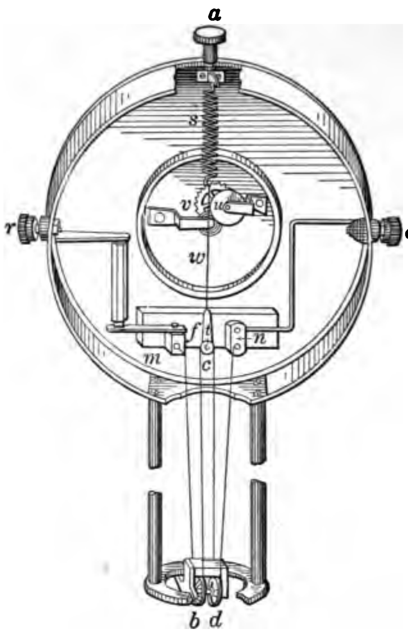



Fig. 171.—Interior of Hot-Wire Voltmeter, showing Construction.

to the head in order to keep the drawing within limits.) From this pulley the wire returns and is passed around a small pulley *c*; thence, it is led around the second pulley *d* and finally terminates at the small brass block *n*. The brass pieces *m* and *n* are supported by a block of insulating material *f*, which is fastened to the case of the instrument; *m* and *n* are connected each to one of the binding posts *r* and *e*, which are insulated by fiber collars from the brass casing.

The small part *c*, referred to as a pulley, acts as such only during the wiring of the instrument, in order to facilitate equalization of the tension in the two halves of the wire; the

expansion of the wire when the apparatus is subsequently used does not cause this pulley to rotate. It is fixed by a small screw passing loosely through its center to one end of a

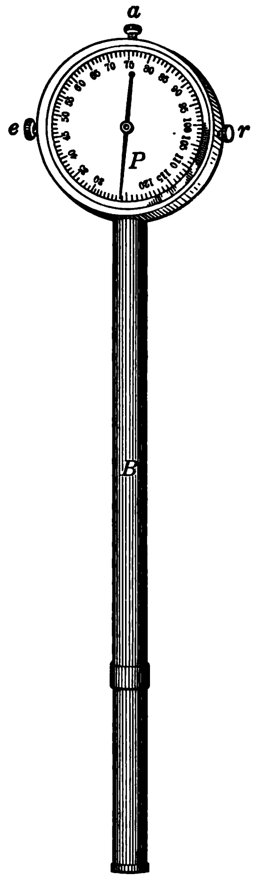



Fig. 172.—Hot-Wire Voltmeter.

thin brass strip *t*, the other end of which has attached to it a fine platinum wire *w* connected to the spiral spring *s*. The tension of this spring, which can be varied by means of the adjusting screw *a*, keeps the wire taut.

When the main terminals *r* and *e* are connected to points in a circuit at different potentials, a current passes, say, to the block *m,* then through the entire length of the four stretches of the expansion wire to the block, *n,* and thence to the other terminal *e.* This current heats the wire, which expands, and the slack is immediately taken up by the spiral spring *s* so that the small brass strip *t* and the wire *w* are moved through a distance equal to the expansion of two lengths of the heated wire.

**559. How does the expansion of the platinum silver wire in the voltmeter, Fig. 171, show the voltage of the current passing through it?**

Through the medium of a jeweled watch movement. The wire *w* is led around a small pulley *u,* Fig. 171, fixed upon the same spindle with a toothed wheel *v,* which gears into a small pinion the spindle of which carries a long pointer *P* passing over a graduated dial shown in Fig. 172. When the wire is expanded by the current, the spring *s* causes the pulley *u* to turn through a small angle, and with it also the wheel *v;* the pinion and the pointer are turned by the wheel *v,* and as the diameter of the wheel is much greater than that of the pinion, the pointer is turned through a large angle by a comparatively small expansion of the wire.

A long, fine wire is used in preference to a shorter one of greater sectional area, because the fine wire heats and cools much more quickly than a larger one would, thus making the pointer come more quickly to rest. By introducing extra resistance the capacity of the instrument can be increased.

**560. Does the hot-wire voltmeter possess any disadvantages?**

It does. Since the meter depends upon temperature differences for its operation, it is extremely sensitive to variations of external temperature, and such variations must be compensated either by increasing or decreasing the tension on the working wire or by providing auxiliary heating strips. Another disadvantage is the constant change of the zero

point, due to the failure of the wire to return to the same point after a measurement, on account of a slight residual strain. Still another objection is the comparatively large current required to operate the meter, rendering it ineffectual for delicate testing.

**561. Show the working parts of an inclined-coil voltmeter and describe the principle of operation.**

The working parts can be seen from the interior view, Fig. 173. They comprise the inclined coil *c* wound in two sections


Fig. 173.—Inclined Coil Voltmeter.

for the high and low reading scales, these sections being connected between the binding posts *a* and *s*, and between *a* and *e*. The coil *c* is inclined about 45 degrees and held in position by an iron support *t*, well insulated from it. This support also contains the bearings for the movable part and the flat spiral springs attached at the top and bottom. The movable part consists of an oblong piece of soft sheet iron *s*, Fig. 174, mounted on the spindle *e f* at an angle of 45 degrees. The pointer *p* is also attached to this spindle, and at such a position with respect to the sheet iron *s* that when the pointer is at zero the sheet iron will lie in the plane of the inclined coil *c c*, as shown in Fig. 174.

When voltage is applied, the lines of force produced by the current in the coil pass through its center, tending to

turn the sheet iron *s* so as to lie at right angles to the plane of the coil *c c*, as in Fig. 175, and deflect the pointer over the

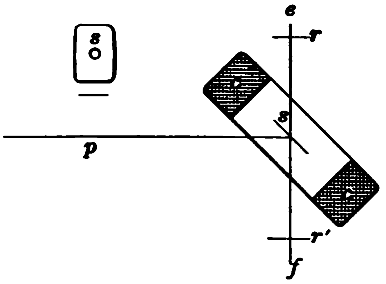



Fig. 174.—Section of Inclined Coil, showing Position of Movable Part under No Voltage.

scale. In both Figs. 174 and 175, *r* and *r'* represent flat spiral springs at the top and bottom of the spindle.

**562. For what purpose are the buttons b and d, in Fig. 173, provided?**

A close examination of Fig. 173 reveals a frame *n* across the top of which is stretched a cord *i*, the whole being sup-

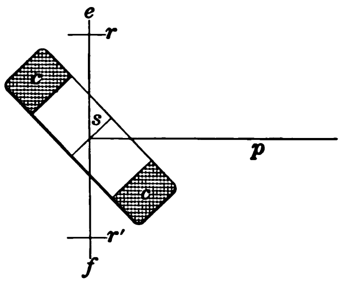



Fig. 175.—Section of Inclined Coil, showing Position of Movable Part with Voltage Applied.

ported by a rod at *r*, which can be given a vertical movement by pressing the button *b*. At the bottom of the guide for the rod *r* is a spring which keeps the frame and cord raised and out of contact with the pointer *p* when the button *b* is not depressed. If, however, the button *b* be pressed down, the

cord *i* will be pressed against the pointer, which travels horizontally between the frame and the cord, thus stopping its vibrations when deflected and facilitating an accurate reading. The button *d* serves for closing the circuit through the meter.

**563. Are the vibrations of the pointer in alternating-current meters more noticeable than in direct-current meters, when taking measurements?**

They are, and for this reason the majority of alternating-current meters are provided with some form of damping device to stop the vibrations of the pointer and thus enable an accurate reading to be taken within a reasonable time after the circuit through the meter has been closed.

## ALTERNATING-CURRENT STATION VOLTMETERS

**564. Do alternating-current station voltmeters differ greatly from alternating-current portable voltmeters?**

Many of them are designed along the same lines as the alternating-current portable meters previously described.


Fig. 176.—Round Type of Station Alternating-Current Voltmeter.

Their construction, however, differs from the portable instruments in order to adapt them for station work, but follows that of the direct-current station meters already shown.

Two typical forms of alternating-current station voltmeters are illustrated in Figs. 176 and 177. Both have iron cases, and graduated scales large enough to be read from a considerable distance. It will be noticed that most alternating-current meters have divisions of varying length at different parts of the scale. Although a uniformly-spaced scale is best,

Fig. 177.—Horizontal Edgewise Type of Station Alternating-Current Voltmeter.

where this is obtained at the expense of accuracy in the mechanism it is not so desirable as an accurate meter with a partly uniform scale.

Ordinarily, the cases of alternating-current meters reading up to and including 150 volts contain the resistance coils also, but with voltmeters of higher reading external resistances are used.

**565. How should an alternating-current voltmeter be connected to a high-potential circuit?**

For potentials much over 750 volts it is not customary to use a multiplier in connection with the voltmeter. Instead, a step-down potential transformer is used, its high-pressure winding being connected across the high-potential circuit and its low-pressure winding to the instrument. A separate transformer is preferably used for this purpose. It is, of course, necessary where a transformer is used, to multiply the reading on the voltmeter by the ratio of the transformer in order to ascertain the circuit voltage.

**566. Is there any instrument for measuring high alternating-current voltages directly?**

Yes; electrostatic voltmeters are used for this purpose.

**567. Illustrate and describe a common form of electrostatic voltmeter.**

Fig. 178 shows one of these instruments. In this form the meter is constructed to measure pressures up to 10,000 volts. The movable aluminum plate *a a* is pivoted on a horizontal axis between the two stationary brass plates *c c* and *d d*. One lead from the pressure main is connected to the terminal *b* on the left-hand side of the enclosing case *e*, which latter may be either of wood or hard rubber; this terminal is permanently connected to the plates *c c* and *d d*. The other lead from the main is connected to the terminal *r*, which, in turn, is per-

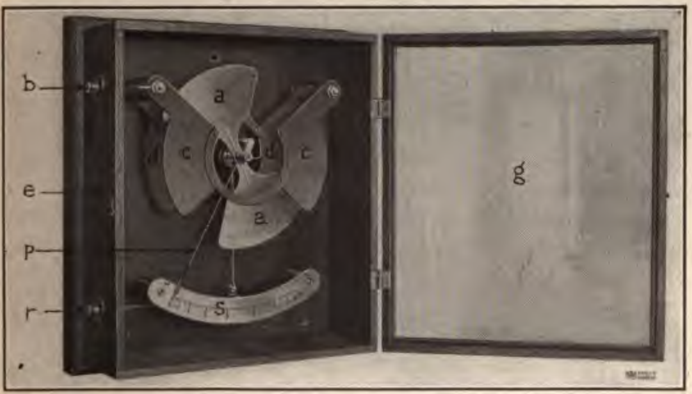



Fig. 178.—Electrostatic Voltmeter for Measuring Pressures up to 10,000 Volts.

manently connected to the spindle of the plate *a a*. This plate carries a pointer *p*, which indicates by its position over the scale *s*, the potential difference between the mains.

With no pressure existing between the mains, the plate *a a* is midway between the two plates *c c* and *d d*. When, however, there exists a difference of potential between the plates *c c* and *d d*, and the plate *a a*, there will be an attraction between them which will increase in proportion to the square of the potential difference, thus drawing the plate *a a* further and further in between the two plates *c c* and *d d*, and con-

sequently carrying the pointer over the scale. The plate *a a* will come to rest when the force due to the electrostatic attraction balances that of gravity.

The glass door *g* is supposed to be closed when the readings are being taken. Owing to the great sparking distance of alternating currents, the electrostatic voltmeter should not be subjected to a pressure greater than 70 per cent. of the maximum for which it is rated, unless discharge points are connected in multiple with its terminals.

**568. What is meant by "discharge points"?**

Discharge points are usually formed by inserting steel needles *s* and *s′*, Fig. 179, in brass holders *b* and *b′*, which pass through insulated supports *m* and *n*. The brass holders

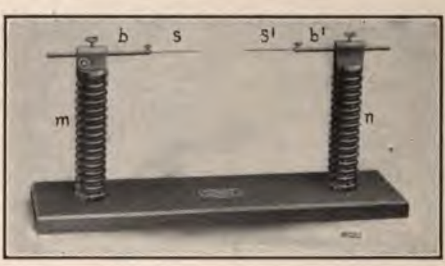



Fig. 179.—Discharge Points for Use in Connection with Electrostatic Voltmeter.

should be capable of being moved back and forth in a horizontal line, so that the distance between the needles, which point toward each other, may be varied. The functions of the discharge points are to protect the voltmeter from higher voltages than it is adjusted to measure and also to check the reading on the scale of the voltmeter.

**569. How is one to know the proper distance apart at which the needles should be set in measuring a certain voltage?**

Reference should be made to a curve showing the relation between the distances from needle-point to needle-point and

the voltages which will jump these distances. Such a curve is shown in Fig. 180. Having determined the proper distance

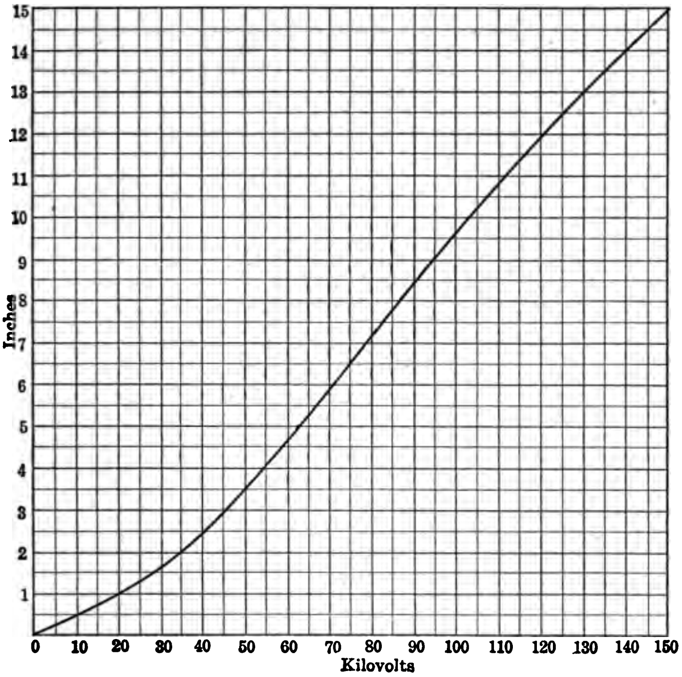



Fig. 180.—Curve of Sparking Distances for High Pressures.

corresponding to the voltage to be measured, the points of the needles are separated this amount.

**570. Must any special precautions be observed in using electrostatic voltmeters for measuring high potentials?**

Care must be taken to make the necessary connections to the wires before the voltage is on the circuit. Rubber gloves and other insulating devices used by electricians in working on live low-pressure circuits are absolutely worthless as protection from voltage such as would ordinarily be measured on electrostatic voltmeters. It is also important never to touch the case, or in fact any part of the instrument, when

in use, except the rubber handle, as the leakage may be sufficient to cause a dangerous shock.

At each discharge, that is, when a spark passes between the needle-points, the points of the needles become fused into knobs by the spark. This changes the conditions upon which the reference curve of sparking distances is based, and must be remedied by replacing the needles with new ones before the next measurement. Care must be taken, however, to open both switches connecting the measuring apparatus to the high-potential circuit before making the change.

Two single-pole switches must be used, one in each side of the circuit joining the measuring apparatus to the high-potential wires. The switches must be placed sufficiently far apart that there will be no possibility of the applied voltage jumping across them, and they should be mounted vertically so that gravity will tend to open the switch blades rather than close them. Under no circumstances should a double-pole switch be used in place of the two single-pole switches just mentioned, on account of the possibility of the voltage arcing across.

**571. Can pressures higher than 10,000 volts be measured directly?**

Yes, pressures up to 100,000 volts can be measured directly on the electrostatic balance shown in Fig. 181, or by use of the spark gap, Fig. 179, in connection with the curve, Fig. 180.

**572. Describe the electrostatic balance.**

Referring to Fig. 181, the fixed portion of the meter is shown at *B*, the enclosing case being broken away to show the interior; *B* is a brass plate, supported above a slate base *s* by three glass pillars *p p p*. The movable portion consists of an aluminum disk *v*, suspended by long links from the short end of the balance arm *i*. The balance arm indicates, by its position over a scale *n*, the potential difference between the two plates *v* and *B*. A brake checks the oscillations of the pointer. In this instrument it consists of a weighted cord

suspended from the top of the case and pressing lightly against the balance arm *i*, as shown. A heavily insulated wire passes through the glass tube *c*, and makes contact with the brass plate *B*. The end of this wire marked *b*, forms one

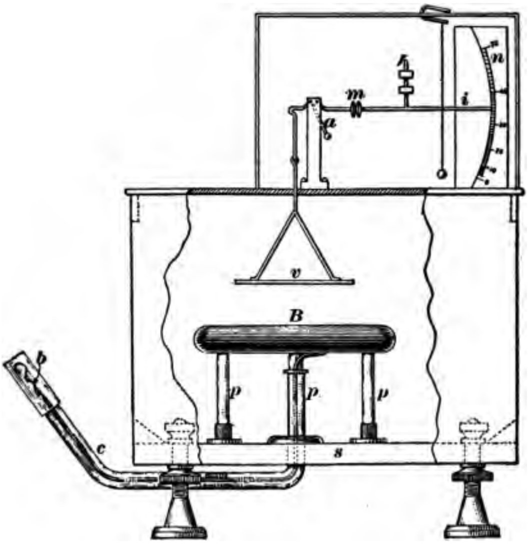



Fig. 181.—Electrostatic Balance for Measuring Pressures up to 100,000 Volts.

terminal of the instrument. The aluminum plate *v* is grounded on the enclosing brass case by means of its support, which, as seen in the figure, rests on the top of the lower case. Any portion of the brass case may, therefore, be used as the other terminal of the instrument.

A set of weights for use on the arm at *m* greatly widens the range of the instrument. When adjusting the weights or moving the instrument, the movable portion is held in a stationary position by pressing the lever *a* in line with the support. The electrostatic balance, by the use of the weights just mentioned, is designed to measure pressures from 5000 to 100,000 volts.

**573. What precautions should be observed in using an electrostatic balance?**

The same precautions specified for the electrostatic voltmeter in Answer 570.

**574. Have static voltmeters or balances any special advantages for measuring voltages of ordinary value?**

They are not influenced by external magnetic fields nor by the frequency of the current. They are direct-reading on either direct- or alternating-current circuits, require an extremely small consumption of energy to operate them, cost little in comparison with other forms of voltmeters, and require no reducing transformers. They are particularly valuable in high-tension plants as a guide for the attendants regarding whether the circuits are alive.

**575. Have electrostatic meters any special disadvantages?**

They do not give as accurate results as other types of voltmeters, the error being usually between 1 and 2 per cent.

## ALTERNATING-CURRENT PORTABLE AMMETERS

**576. Are not the working parts of alternating-current portable ammeters designed along the same lines as the alternating-current portable voltmeters previously taken up?**

Some are and some are not.

**577. Mention some common forms of alternating-current portable ammeters that differ in design from the instruments previously considered.**

Two of the most common and accurate alternating-current ammeters are the Siemens dynamometer and the Kelvin balance. The Siemens dynamometer is shown in Fig. 182, and the principle of its operation is illustrated by Fig. 183. The main parts of this instrument are two coils represented by the wires *a a′* and *b b′*, at right angles to each other, the coil

$a\ a'$ being stationary and, as shown in Fig. 182, bound securely to the support $d$ by the band $e$. It is composed of many more turns than the coil $b\ b'$, called the "movable coil," which is suspended on a steel pivot that rests in an agate cup and is free to move about its vertical axis.

The current to be measured passes through the two coils

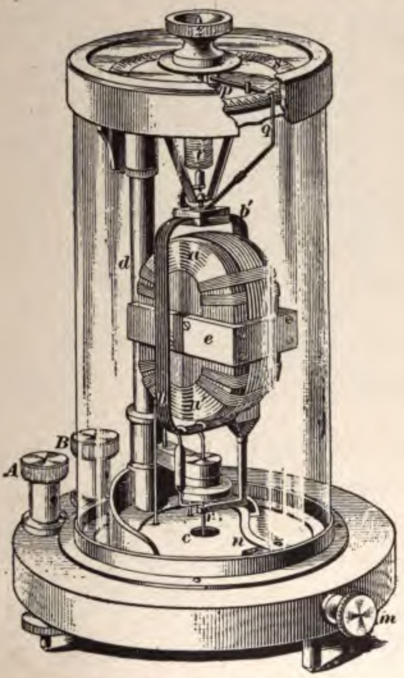



Fig. 182.—Siemens Dynamometer.

in series, and the movable coil tends to turn so as to place its plane parallel to the plane of the fixed coil, in order that the lines of force produced by the two coils may coincide in direction. This tendency of the movable coil to turn about its vertical axis is counterbalanced by the force of the spring $t$, one end of which is adjustable by hand by means of the knob $z$. Permanently attached to the knob $z$ is the pointer $p$,

which indicates by its position above a graduated scale *s*, the number of degrees through which the end of the spring has been adjusted.

In Fig. 182, part of the top of the glass case and a section of the brass rim have been broken away to show the scale, pointer and index. The index *q* permanently attached to the

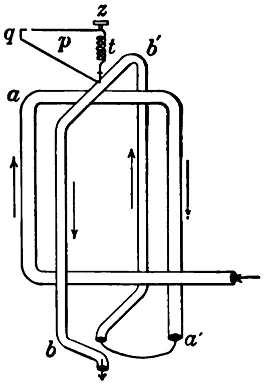



Fig. 183.—Illustrating the Principle of Siemens Dynamometer.

movable coil indicates zero on the scale *s* when the plane of the movable coil is at right angles to that of the fixed one.

**578. Explain the method of measuring a current on the Siemens dynamometer.**

First, the knob *z* should be turned so that the pointer *p* indicates zero. If the index *q* is not then at zero, the instrument is not level, and the adjustable screws on which the instrument rests must be turned until the index *q* is at zero, care being taken that the rod *r*, which forms one terminal of the movable coil, and makes contact with the fixed coil in the mercury cup *c*, hangs centrally in the cup.

Having made this adjustment and connected the binding posts *A* and *B* in series with the circuit, current is allowed to pass through the coils. The movable coil will no longer remain at right angles to the fixed coil, but will turn about it, thus carrying the index *q* off the zero point. The knob *z*

should then be turned until the index $q$ again points to zero. When this occurs the pointer $p$ will be found to have been turned through a certain angle indicated by the number of degrees on the scale.

**579. What relation is there between this angle and the current passing?**

The force of torsion or twist is proportional to the angle of torsion. As the angle through which the screw is turned in order to keep the movable coil at zero is an exact measure of the torsion applied, the force necessary to produce that angle must be proportional to the force acting between the two coils and due to the current circulating through them. This force varies as the square of the current strength, so that the current strength is proportional to the square root of the angle of torsion.

The best method for determining the current for a given angle is to use a calibration curve, which is furnished by the makers of the instrument, and is drawn when the instrument is being standardized; this shows directly the current corresponding to each number of degrees on the scale.

**580. What are the advantages and disadvantages of the Siemens dynamometer for measuring currents?**

Accurate results can be secured in measuring both direct and alternating currents, and these results are independent of the frequency and form of the alternating current. Having no iron or permanent magnets, the constancy of the meter depends upon the spring $t$, which experience shows does not change from year to year.

The instrument, however, must be kept carefully leveled and free from outside magnetic influences. Not being a direct-reading instrument, some time is required for obtaining a reading, and the dynamometer is of little practical use when the current fluctuates rapidly. Whenever it is necessary to move the instrument, the screw $m$, Fig. 182, must be turned. This raises the movable coil by raising the arm $n$, and holds

it firmly in place, thus preventing any injury to the suspension system.

**581. What are the usual sizes in which Siemens dynamometers are made?**

They are made in sizes of 20, 60, 200 and 500 amperes.

**582. Explain the operation of the Kelvin balance.**

The Kelvin balance depends for action upon the force either of attraction or repulsion, exerted between adjacent portions

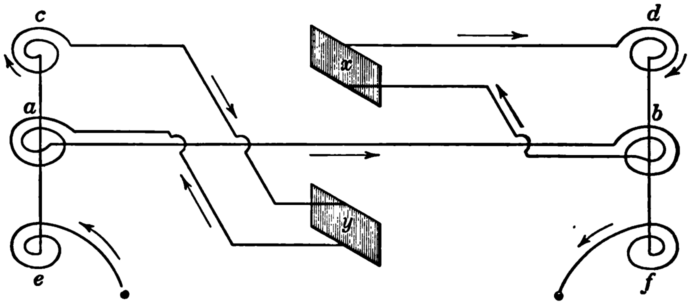



Fig. 184.—Diagram of Kelvin Balance.

of an electrical circuit. In order that this magnetic force shall make itself evident and be measurable, it is of course necessary that one portion of the circuit be movable. As suggested by the name, the movable part takes the form of a balance arm supporting at each end a coil of wire, as shown at *a* and *b* in Fig. 184, which represents a diagram of the balance. The balance arm is forced upward or downward by the action of the stationary coils *c* and *d*, *e* and *f*. The movement of the balance arm is opposed by weights, which are placed in a carriage represented at *u*, Fig. 185, where a perspective view of the instrument is shown. Hence, by adjusting the weights and the position of the carriage *u* along the balance arm *m n*, a certain position of the carriage may be found where equality exists between the force exerted by the electric current and the opposing force of gravity; this equality being attained when the pointer *p* at each end

of the balance indicates zero. The strength of the current is then read off approximately on the upper scale, or with greater accuracy on the lower or finely divided scale.

The various coils are wound with coarse or fine wire, according to the range or use of the instrument, and the movable coils *a* and *b* are connected so as to produce opposite polarities on their upper faces; one having a north pole uppermost, the other a south pole uppermost. This produces an "astatic" system, so that the meter is not affected by the earth's field nor by nearby magnetic fields, providing the instrument is placed in such position or at such a distance as to render the nearby field practically uniform in its effect on the movable coils. The stationary coils are so connected as to act together in forcing the balance arm one way or the other.

The balance arm is supported at its center by two trunnions indicated in Fig. 184 by $x$ and $y$. These trunnions have each

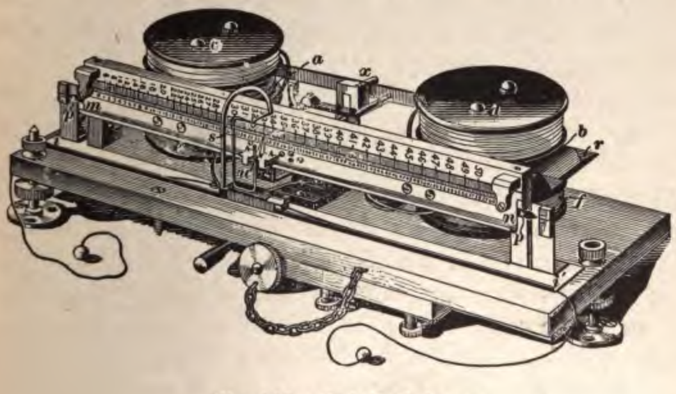


Fig. 185.—Kelvin Balance.

an elastic ligament of fine wire through which the current passes into and out of the circuit of the movable coils. If the ligaments become stretched after the instrument is standardized, the index at one end of the balance arm will be found to be below the middle line on the vertical scale

when the index at the other end is pointing at zero. The error so introduced will be a small one, but may be eliminated by loosening the screws and adjusting the scales so that the difference between the zero point on the scale and the position of the pointer is equally divided on both sides.

**583. Can the range of the Kelvin balance be increased by the use of weights?**

Yes; each balance is provided with four pairs of weights for this purpose, of which the carriage *u*, Fig. 185, and its counterpoise placed in the trough *r* at the end of the balance arm constitute the first pair. The carriage slides on an approximately horizontal graduated arm *m n*, attached to the balance arm. The apparatus shown at *s* is used to move the carriage *u*, and consists of a slider, one arm of which projects upward between the projecting arms of the carriage. By means of an attachment to the curved arm of the slider, it is possible to cause a very small movement of the carriage. The slider is moved along the guide *i i'* by means of the cords attached to both ends. By this arrangement an adjustment of the carriage is easily made by hand, even when a glass case is placed over the working parts to eliminate any errors introduced by air currents acting on the balance arm.

When the range of the instrument is to be increased over that obtainable with the first pair of weights mentioned, a larger counterpoise is placed in the trough *r* in the place of the one corresponding to the weight of the carriage alone. The weight corresponding to this larger counterpoise is placed on the carriage *u* and a balance obtained, as previously described, by moving the carriage along the graduated scale. The strength of the current is then read off approximately on the upper scale, or with greater accuracy on the lower or finely divided scale as before. The weights and counterpoises are adjusted in the ratio of 1 : 4 : 16 : 64, so that each pair makes the range of the balance double that of the next lighter weight and counterpoise.

**584. In what sizes are the Kelvin balances made?**

They are made in sizes of 1/100 to 1 ampere, 1/10 to 10 amperes, 1 to 100 amperes, 6 to 600 amperes and 25 to 2500 amperes. These Kelvin balances are designed to carry their maximum current sufficiently long for taking a reading, and 75 per cent. of this current continuously.

**585. What advantage, if any, does the Kelvin balance possess over the Siemens dynamometer?**

The Kelvin balance is a much more accurate instrument; in fact, it is the most accurate of all instruments for measuring alternating currents and is frequently used as a standard in the calibration of other ammeters. It is also a direct-reading instrument, whereas the Siemens dynamometer is not, and is equally well adapted to the measurement of both direct and alternating currents.

**586. Mention any precautions that should be observed in the use of the Kelvin balance.**

For the most accurate results a glass case should be placed over the working parts while taking a measurement, in order that air currents may not affect the movement of the balance arm.

To insure accurate observations either when reading the position of the carriage or in adjusting the zero position, use should be made of the lens provided for this purpose. The vibrations of the balance arm may be checked so as to facilitate reading, by bringing the slider arm, which moves the carriage, lightly in contact with it in such a way as to produce a little friction without moving the carriage.

## ALTERNATING-CURRENT STATION AMMETERS

**587. Upon what principles does the action of alternating-current station ammeters depend?**

The usual types of these meters depend for their operation upon the same principles made use of in the alternating-current portable voltmeters already explained. There are,

therefore, alternating-current station ammeters of the moving coil type operating by reason of the mutual magnetic attraction between two coils through which the current is led; alternating-current station ammeters of the inclined coil type as


Fig. 186.—Interior of Alternating-Current Station Ammeter of Inclined Coil Type.

shown in Fig. 186; alternating-current station ammeters of the hot-wire type for special high-frequency currents; and there are also alternating-current station ammeters of the induction type.

**588. Illustrate and describe an alternating-current station ammeter of the induction type.**

Referring to Fig. 187, which shows in two views the front and side of an ammeter of this type designed to be mounted with its face flush with the front of the switchboard, it is seen that the scale which measures 14.5 inches in length, on account of being circular, enables the meter to be made small —only 9 inches across—so that it occupies comparatively little space on the switchboard.

The mechanism is shown in Fig. 188, the case and scale having here been removed. Referring to Fig. 189, which is a diagram of the mechanism, the outline of the laminated iron circuit with its annular air gap can be plainly seen.

The movable part comprises an aluminum drum *p p s s* rotating in the air gap of the electromagnet formed by the

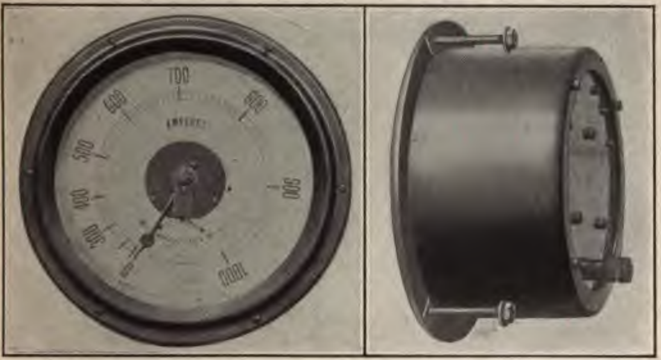



Fig. 187.—Alternating-Current Station Ammeter of Induction Type.

laminated iron circuit just mentioned and the coils *P P* and *S S*, through the former of which passes the current to be

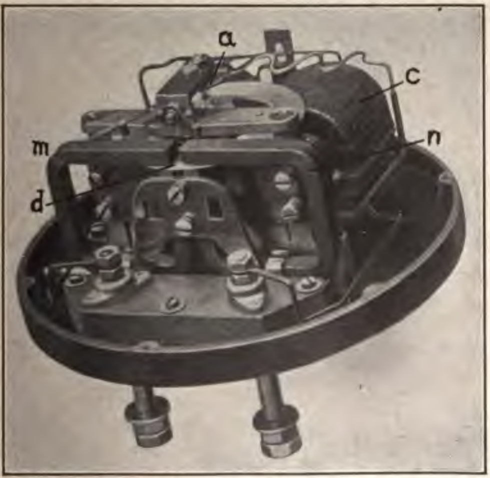



Fig. 188.—Ammeter in Fig. 187 with Case and Scale Removed.

measured. The coils *S S* constitute the secondary winding, which is short-circuited on itself. The primary winding *P P*

and the secondary winding *S S* bear the same relation to each other as the primary and secondary windings of a current transformer and their currents are similarly related. The dotted lines represent the various magnetic fluxes produced by the currents in the coils. Thus, the operation of this

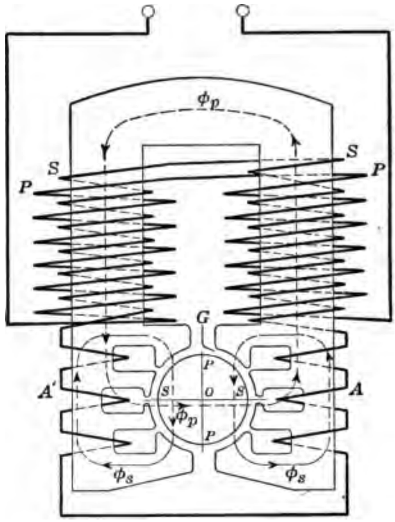



Fig. 189.—Diagram of Ammeter in Fig. 187.

induction type of meter is due to a combination of the actions in a current transformer and an induction motor.

The movable aluminum drum carries a shaft on which is mounted the pointer and an aluminum damping disc *d*, Fig. 188, the latter of which is under the influence of two permanent magnets *m* and *n*. The damping action of the magnets on the disc not only facilitates readings being taken on circuits carrying fluctuating loads but also prevents a violent swing of the pointer on overloads or short-circuits. One of the electromagnet coils can be seen at *c* in Fig. 188, and at *a* is a spiral controlling spring which restrains the rotation of the movable shaft of the meter when in circuit, which otherwise would revolve continuously as a motor.

**589. What are the points of relative superiority of the commonly used types of alternating-current station ammeters?**

Disregarding the hot-wire type, which is very seldom used, a fair comparison of the best representatives of the moving coil type, the moving iron or inclined coil type, and the induction type is given in the following table:

| | Moving Coil | Moving Iron | Induction |
|---|---|---|---|
| Initial Accuracy | Highest | Good | Good |
| Ratio of Torque to Weight | Low | Low | High |
| Ruggedness | Delicate | Not delicate | Rugged |
| Permanence | Easily deranged | Fair | Best |
| Frequency Errors | None | Slight | Slight |
| Temperature Errors | Slight | Slight | Slight |
| External Fields | Heavy shielding required * | Heavy shielding required † | Very slightly affected * |
| Scales | Short | Short | Great length |
| Repairs | Difficnlt | Easy | Simple |

* Affected by stray fields of same frequency only.
† Affected by any alternating-current or direct-current stray field.

**590. What provision is made for safely measuring alternating current in high-potential circuits?**

A series transformer such as shown in Fig. 190, is used in connection with the ammeter. In this General Electric trans-


Fig. 190.—Series Transformer for Use with Ammeter in Measuring Current on Circuits up to 15,000 Volts.

former, the primary winding, denoted by *p*, is connected in circuit by means of the terminals *a* and *c*, and the secondary winding *s* is joined to the meter by means of its terminals *e*, etc. The laminated iron core around which both windings are wound is shown at *i*. This transformer can be used on circuits having voltages up to 15,000 with currents up to 800 amperes, and will give a secondary current up to 5 amperes.

## WATTMETERS

**591. For what purpose is a wattmeter used?**

To measure the power, in watts, being supplied to a circuit.

**592. Is the wattmeter a direct-reading instrument?**

Yes, it gives instantaneous values of the watts in a circuit upon the pressing of a key.

**593. Illustrate and describe the construction of a wattmeter.**

A wattmeter of the portable indicating type depending for its operation upon the magnetic action between movable and fixed coils is shown in Fig. 191 and a diagram of its construc-


Fig. 191.—Portable Indicating Wattmeter.

tion and connections is given in Fig. 192, the corresponding parts in both illustrations being lettered alike. *A* and *B* are the current terminals, and *a*, *b* and *c* the pressure terminals, *a* and *c* being the ones used when the pressure is not over 75 volts, and *a* and *b* when the pressure is between 75 and 150 volts.

The interior circuits and exterior connections of this wattmeter are shown in Fig. 192, where *T* is an alternator supplying current to the circuit in which *x y* represents a resistance

or load, such as lamps or motors. If, now, it be desired to measure the power in watts supplied to the circuit *x y*, the wattmeter is connected as shown, the pressure coils represented by the light zigzag lines at *e d* being connected to the same side of the load *x y*, as are the corresponding current

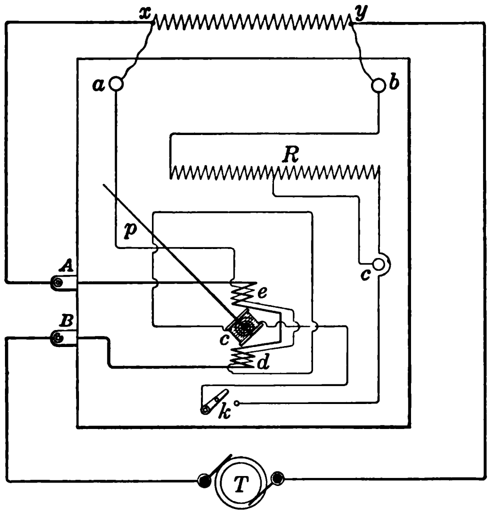



Fig. 192.—Circuits through the Indicating Wattmeter in Fig. 191 and Its Connections for Use.

coils represented by the heavy zigzag lines at *e d;* this method of connection is followed to avoid a high potential difference between the coils.

**594. How does this form of wattmeter operate?**

Supposing the current enters at *B*, passes around the current coils *d* and *e* in opposite directions and out at *A*. In the pressure circuit the current at the same instant enters at *a*, passes down the fine wire, around the coils *e* and *d* in the opposite direction to the former current (the wire of the two sets of coils being wound in opposite directions), and then passes through the movable coil *c*, the key *k* and the resistance *R*, leaving the instrument at *b*.

The two circuits through the coils *e* and *d* are wound in opposite directions in order to neutralize the deflection which would be caused by the potential coil *c* if the load circuit *x y* were opened. If it were not for this differential winding there would be a deflection representing a number of watts, but as no power would be supplied to the circuit *x y*, and as it is intended the instrument should measure only the power actually transmitted, any deflection of the coil *c*, and consequently of the pointer *p*, would be incorrect.

**595. What is the limiting range of measurements for the wattmeter in Fig. 191?**

This meter is made for a maximum reading of 150 watts,—this with a maximum safe current-carrying capacity of two amperes, normal one ampere, and a maximum voltage of 150, which is sufficient for measuring the watts expended in incandescent lamps and other devices using small amounts of electrical energy.

Unless it is definitely known that the pressure to be measured does not exceed 75 volts, the pressure leads should be connected to the terminals *a* and *b*, which take in the total resistance *R*, Fig. 192; if, then, the pressure is found to be 75 volts or over, the connection is all right, but if under 75 volts the lead connected to *b* should be changed to the terminal *c* as this takes in only half the resistance *R* and consequently gives a more accurate reading.

For higher voltage than 150, a multiplier is connected in series with the pressure leads, and the readings on the scale are multiplied by the proper multiplying factor which is obtained as described in Answers 530 and 531. Pressures up to 2250 volts may thus be measured in connection with the current, providing the latter does not exceed the one ampere limit of the meter.

**596. Are portable wattmeters made in any other form than that shown in Fig. 191?**

Yes, another very common type of portable wattmeter is that shown in Fig. 193. This meter operates by reason of

the magnetic attraction between the inclined coil *c* and an oblong piece *a* of soft sheet iron mounted on a spindle to which the pointer *e* is also attached. The reader will recognize this construction as similar to that in the inclined coil

Fig. 193.—Indicating Wattmeter of Inclined Coil Type.

voltmeter shown in Fig. 173 and described in Answer 561, and consequently will understand the operation of this meter without further explanation.

## RECORDING VOLTMETERS, AMMETERS AND WATTMETERS

**597. Do recording voltmeters, ammeters and wattmeters operate on the same principles as the indicating voltmeters, ammeters and wattmeters previously described?**

No. Recording meters, as usually made for direct- and alternating-current circuits, operate by the action of a solenoid either upon a combination disc core armature or a plunger.

**598. Illustrate one of these recording meters that operates on the first principle mentioned, and describe its operation.**

Figs. 194 and 195 show, respectively, front and inside views of a common form of recording ammeter for direct current up to 600 amperes. In Fig. 195 the case has been removed to show the working parts. The solenoid, consisting of two coils of wire, is enclosed at *a a*, and its effect depends

upon the current passing through the meter which is connected in series with the circuit at the terminals $m$ and $s$.

The moving element consists of a combination disc armature and light iron core, mounted on a non-magnetic shaft extending through the solenoid. Each end of this shaft is supported by a vertical steel spring. The combination disc core armature is attracted toward the stationary solenoid when the current flows. Although the actual distance that the armature itself moves is small, it transmits an angular motion to the pen arm $b$, resulting in a wide range of movement. At $f$ is a damping device which consists of a box filled with oil in which moves a light vane attached to the armature.


Fig. 194.—Recording Ammeter.

A circular disk is revolved about the center $c$, with a uniform rate of motion, by means of the clock-work shown at $d$, Fig. 195. On this disk is fastened a paper dial $e$, Fig. 194, on which are printed circles, as at $o$, etc., to indicate the current when the pen arm $b$ is swung outward from the inner circle

onto or near one of the other circles. There are also radial lines, as at *n*, extending from the center to the outer rim of the dial, marking the divisions of time, each line representing one hour of the twenty-four and being so designated at the outer extremities. Intervening lighter lines indicate fractions

Fig. 195.—Interior of Recording Ammeter in Fig. 194.

of hours. The end of the arm *b* is provided with a self-inking pen, which traces a line on the dial as the latter revolves, and thereby continuously records the current in the circuit to which the meter is connected.

**599. Is there an instrument called a maximum-current recorder?**

Yes. The maximum-current recorder is employed to determine the greatest strength that the current attains during any given period of time. If used in connection with a recording watt-hour meter it furnishes a means for determining maximum current demand and load factor as a basis for

rates on systems where the charges are governed by the maximum demand and power delivered. Although the instrument records the maximum demand of the connected load it does not indicate the time at which the maximum occurs.

**600. Illustrate and describe the operation of a maximum-current recorder.**

The diagram, Fig. 196, illustrates the principle of operation in a simple form of such a meter. One side of a circuit in which it is desired to determine the maximum use of current is opened and connected to the terminals *a* and *b* of the meter. The wire *c* which connects these terminals passes around the glass bulb *m*, which is hermetically sealed and connected to the glass tube *d* holding a liquid *v*.

The heat developed by the current in the wire *c* expands the air in the bulb *m*, which forces the liquid down in the

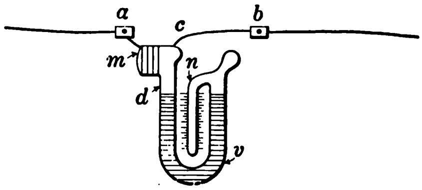



Fig. 196.—Diagram of Maximum-Current Recorder.

left-hand column of the glass tube and up in the right-hand column. If the current be sufficiently high, the liquid in the right-hand column will run over into the central tube *n*, where it must remain until the instrument is readjusted. A scale back of the tube *n*, calibrated in amperes and watts, enables the height of the liquid in the tube *n* to be measured in these terms. If the maximum load lasts 5 minutes, 80 per cent. will register; if 10 minutes, 95 per cent. will register and if 30 minutes, 100 per cent. will register.

After a reading has thus been taken and recorded for a certain length of time, the liquid is returned to the outer tubes by tipping up the apparatus, which is hinged at the top to permit of this being done.

**601. Are maximum-current recorders made in any other form?**

Yes, there is another form in which the indications are given by a pointer on a scale. This instrument comes as a part of a watt-hour meter for use on alternating-current circuits and operates on the induction principle. The shafts of the two pointers are geared together, the maximum demand being indicated by a pointer sweeping over a 4-inch scale and the watt-hour load on a 4-dial counter.

**602. What is a watt-hour meter?**

A recording wattmeter which registers on an indicator the amount of electrical energy in the circuit in which it is connected; in other words it records the watts of power operating over a given time in hours, that is, the watt-hours. The watt-hour meter is installed on the premises of the consumer and the monthly readings taken from it form a basis for reckoning the amount of the bill for the quantity of electricity used.

**603. Show the working parts of a watt-hour meter and explain their operation.**

Fig. 197 shows the working parts of a watt-hour meter for direct-current circuits up to 600 volts. It registers directly on the dial *d*, the kilowatt-hours up to 30 kilowatts, and comprises a small direct-current motor *m f* for causing rotation of the spindle or shaft *i* that operates the pointers on the dial, and a generator *p g* which provides the necessary load or drag so that the rotation is kept down to the desired amount.

The motor is without iron in its fields and armature. The armature *m* is spherical and is composed of very fine wire wound on a light paper shell; it revolves within the circular shunt-field coils *f*, which are wound with ribbon wire, and placed as near each other as possible on either side of the armature without touching it. The armature rotates at a very low speed so it has little or no counter electromotive force. The armature current is therefore independent of

the speed of rotation and is constant for any definite potential applied at its terminals. The torque of the motor being proportional to the product of its armature and field currents, must vary directly as the energy passing through its coils.

In order, then, that the meter shall record correctly, it is necessary only to provide some means for making the speed proportional to the torque, and this is done by applying a load or drag, the strength of which varies directly as the speed. The electromotive force induced in a conductor pass-

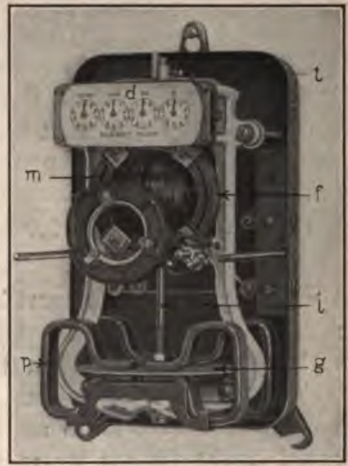



Fig. 197.—Watt-Hour Meter for Direct-Current Circuits.

ing through a field of constant strength is proportional to the number of magnetic lines of force cut in a given time; therefore, if the resistance of the conductor remains constant, the drag is proportional to the speed. This condition is provided by mounting an aluminum disk *g* on the motor shaft *i* and having it pass between the jaws of the permanent magnets *p*, etc., the latter of which furnishes the field of constant strength referred to above.

The terminals of the meter are located at *t*, from which the current is led through a commutator on the shaft *i*, above

the armature *m* and behind the dial *d*. It is also at this point that the motion of the shaft is transmitted to the pointers on the dial through a system of gear wheels.

**604. On alternating-current circuits should a different form of watt-hour meter be used than on direct-current circuits?**

A watt-hour meter operating on the induction principle,

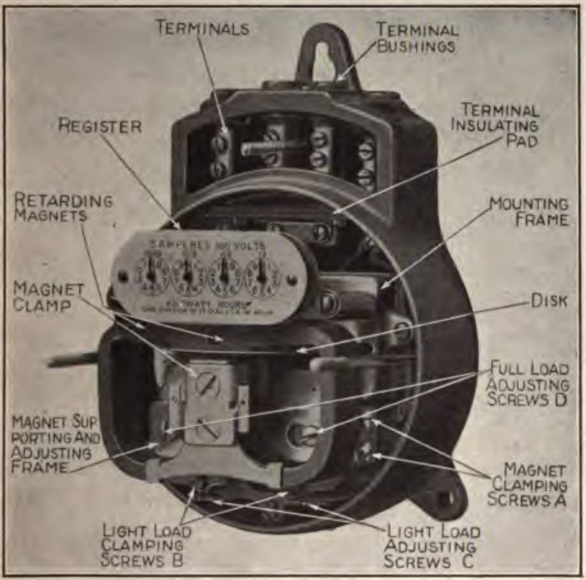



Fig. 198.—Watt-Hour Meter for Alternating-Current Circuits, showing Front of Meter with Cover Removed.

without commutator, is preferable for alternating-current circuits.

**605. Illustrate and describe a common form of watt-hour meter for alternating-current service.**

Figs. 198 and 199 show the working parts of a single-phase watt-hour meter, the former the front of the meter with cover removed, and the latter the rear of the meter with the entire

case removed. The working parts comprise principally the field magnets, the moving element, the retarding element, the registering mechanism and the power factor adjustment.

The field magnets comprise both series and shunt coils; the former of few turns and low inductance are connected in series with the circuit to be metered, and the latter of high inductance are connected across the circuit. The currents in

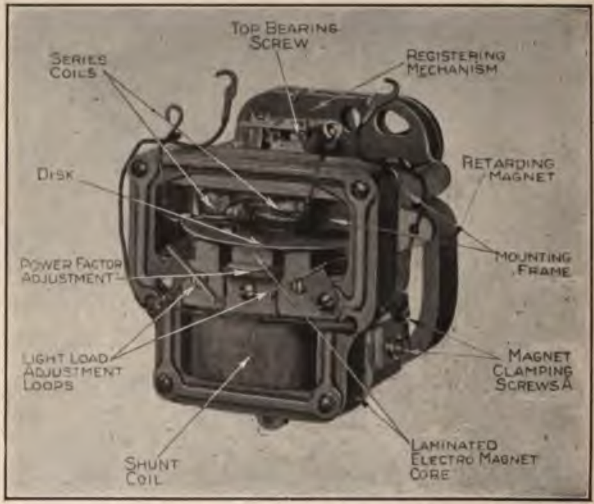



Fig. 199.—Working Parts of Watt-Hour Meter in Fig. 198 removed from Case and shown from the Rear.

the series and shunt coils are 90 degrees displaced with respect to each other when the current is in phase with the voltage (100 per cent. power factor), and the coils are so mounted on the core that the currents in them produce a rotating or shifting field, the strength of which is proportional to the product of the volts, amperes and power factor, and is therefore a measure of the actual power.

The moving element consists of a light metal disk revolving through the air gap in which the rotating field is produced. Currents are induced in it which combine with the rotating field to produce a torque or field proportional to the power

in the circuit and this torque is counterbalanced by the retarding element so that the speed of the disk is exactly proportional to the torque.

The retarding element consists of two permanent magnets mounted on that side of the meter diametrically opposite to the field coils and between the poles of which the metal disk of the moving element rotates. The magnet poles develop an electromotive force between the inner and outer parts of the disk that sets up eddy currents in it which consume the power passing through the field magnet coils.

The registering mechanism comprises the dials, pointers and the gear wheels necessary to secure the required reduction in speed to enable the dials to register directly in watt-hours. A power factor adjustment consisting of a short-circuited loop of variable resistance enclosing part or all of the shunt field flux, and acting like the secondary of a transformer, enables the phase angle between the shunt and series field currents to be made exactly 90 degrees with 100 per cent. power factor in the metered circuit. This is a necessary adjustment to be made in order that the strength of the rotating field be a measure of the actual power in the circuit metered,—a condition upon which the proper operation of the instrument depends.

**606. If the pointers on the dials of a watt-hour meter indicate as shown in Fig. 200, what is the correct reading?**

Considering, first, the position of the pointer on the scale furthest to the right, it is seen to be on *2*. One complete revolution of the pointer on this scale indicates 1000 watt-hours, each of the ten divisions being equal to 100 watt-hours. The *2*, therefore, on the right-hand scale denotes 200 watt-hours. Passing to the next scale to the left, the pointer on this has just passed *6*. According to the figures outside this scale, every complete revolution of the pointer on it denotes 10,000 watt-hours; consequently the *6* point indicates 6000 watt-hours. Thus, the sum of the readings on the two scales thus far considered is 200 plus 6000 or 6200 watt-hours. The

third scale from the right registers considerably over *1*. Since one complete revolution of the pointer over this scale equals 100,000 watt-hours, the *1* denotes one-tenth of 100,000 or 10,000 watt-hours, making the total thus far amount to 16,200 watt-hours. As the pointers on the fourth and fifth scales from the right have not passed *1*, no reading is taken

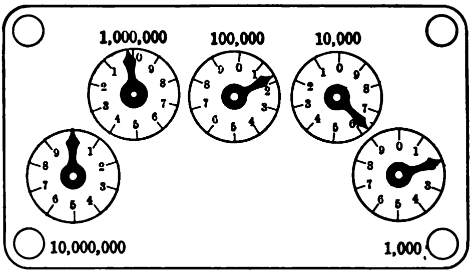



Fig. 200.—Watt-Hour Meter Dial shown to Illustrate the Method of Reading the Scales.

on them, so that 16,200 watt-hours, or 16.2 kilowatt-hours, is the correct reading of the dial illustrated.

In practice, there would be subtracted from this reading the reading taken on the dial the previous month, and the difference would be the number of watt-hours or kilowatt-hours on which the monthly bill is reckoned. Special care should be taken in case the pointer on any scale appears to be exactly on a division, to determine whether the figure on the division has been passed by the pointer. This is determined by referring to the position of the pointer on the scale next to the left, for if the latter has not passed the division near it, it implies the division in doubt has not been passed.

## GROUND DETECTORS

### 607. What are ground detectors?

Instruments or devices for indicating a "ground," or accidental connection between the earth and a conductor intended to be insulated from the earth.

**608. Are ground detectors adapted for use on both low- and high-potential circuits?**

Yes; but in the latter case a more complicated device is necessary than in the former one.

**609. Illustrate and describe a ground detector for low-potential circuits.**

A simple low-potential ground detector is shown in Fig. 201. It consists of two incandescent lamps *c* and *d*, each of the voltage of the low-potential circuit *m n*. These lamps are connected in series with each other, and one of the terminals is connected to the main conductor *m* at *r*, and the other

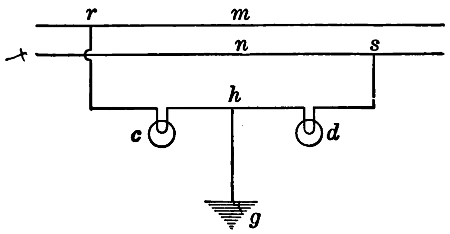



Fig. 201.—Simple Form of Ground Detector for Low-Potential Circuits.

terminal is connected to the conductor *n* at *s*. Between the lamps, at *h*, is " tapped " a wire which runs to the ground *g*.

If the difference of potential between the wires *m* and *n* is the same as the rated voltage of each of the lamps, they will each be supplied with half the rated voltage, since they are connected in series, and will show dull red. If, however, the wire *m* becomes grounded, there will be no difference of potential between the points *r* and *h*, and the lamp *c* will be short-circuited and remain dark. And, since the points *r* and *h* are of the same potential and the full voltage of the circuit exists between *m* and *n*, the full voltage will be supplied between *s* and *g*, or between *s* and *h*, and the lamp *d* will burn brightly. When the ground is on the wire *n*, the lamp *c* will burn brightly and the lamp *d* will be dark. A means is thus provided for instantly determining where and

when a " ground " occurs so that the trouble may be remedied before it has time to develop to any serious extent.

**610. Illustrate and describe a ground detector for high-potential circuits.**

Fig. 202 shows the working parts of one of these instruments. A vane *v*, composed of sheet aluminum, is pivoted at the center *o*, and is free to revolve; it is electrically connected with the ground and has attached to it a pointer *p* which indicates the position of the vane. Secondary fixed vanes,

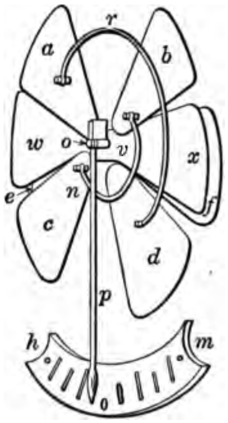



Fig. 202.—Working Parts of Ground Detector for High-Potential Circuits.

shown at *a, b, c* and *d,* are supported on insulators at a short distance from the back and base of the instrument. The wire *r* connects together *a* and *d,* so that the polarity of the pair will be the same when either vane becomes charged. In like manner, *b* and *c* constitute a pair of equal polarity, being connected by the wire *n*. There are two other vanes, *e* and *f,* one behind each end of the vane *v;* they are embedded in the back of the instrument and are in reality not visible, but are shown here in order that their purpose may be clearly explained. The sheets *e* and *f* are the primary vanes, and are connected one to each side of the circuit leaving the

station. These vanes will be charged when there is current on the line wires, and since they are connected one to each side of the circuit, one vane will be charged negatively when the other one is charged positively. Taking any particular instant when the vane $f$ is charged positively, the vane $e$ will be charged negatively. When $f$ is charged positively it will induce a negative charge on the vane $d$, and at the same time $e$ will induce a positive charge on the vane $c$; $a$, being electrically connected to $d$, will also be charged negatively, and $b$ will be charged the same as $c$, or positively. At this instant $d$ will have a tendency to induce a positive charge in the vane $v$ at $x$, but $b$ will have an equal tendency to induce a negative charge there, and the action of the two forces will be neutralized. The same reasoning applies to $w$, and the vane $v$ will therefore remain in the neutral position between the two pairs of secondary vanes, and the pointer $p$ will rest at zero on the scale $h\,m$.

If, now, a ground occurs on the line wire with which the vane $f$ is connected, the vane $v$, being also grounded, will be electrically connected with $f$ and therefore charged positively, or the same as $f$. The vane $b$, however, is also charged positively by induction, and will repel the end $x$ of $v$, while $d$, which is negative, will attract it. In the same manner the vane $a$ will attract and the vane $c$ will repel the end $w$ of the vane $v$. Then, since all of the four secondary vanes tend to revolve the movable vane $v$ in a clockwise direction, the pointer $p$ will move toward $h$ on the scale $h\,m$ and will, by its position, indicate roughly the relative conductivity of the ground. When the ground is on the wire connected to the vane $e$, the pointer $p$ will move toward $m$, for the polarity of each secondary vane will then be reversed.

The working parts, Fig. 202, are mounted on a marble base at the back of the instrument and are enclosed and protected from injury by a glass case. The glass case enables all of the parts except the primary vanes to be plainly seen.

## MISCELLANEOUS STATION INDICATING INSTRUMENTS

**611. Are there any other indicating instruments in common use in the station in addition to those previously considered?**

There is a frequency meter, a power-factor meter and a synchroscope which are worthy of note.

**612. What is a frequency meter?**

A frequency meter, Fig. 203, is used for indicating directly the "frequency" or number of cycles at any moment in an alternating-current circuit. It operates on the induction plan and consists of two voltmeter electromagnets acting in opposition on an aluminum disk attached to the pointer shaft. One of the magnets is in series with a reactor and the other with a


Fig. 203.—Frequency Meter.

resistor, so that any change in the frequency will unbalance the forces acting on the disk and cause the pointer to assume a new position, where the forces are again balanced The frequency meter is not influenced by voltage variations, and its scale is generally calibrated from 20 to 30 for 25-cycle circuits

and from 45 to 75 for 60-cycle circuits. When used on circuits exceeding 100 volts, a transformer is required.

**613. Describe a power-factor meter.**

The power-factor meter, Fig. 204, is used for ascertaining the power factor of an alternating-current circuit. This instrument gives readings which are the ratio of the true watts

Fig. 204.—Power-Factor Meter.

in the circuit (as indicated by a wattmeter) to the apparent watts (the product of volts and amperes).

It operates on the rotating field principle. A rotating field is produced by currents of the metered circuits in angularly placed coils, one for each phase of the system in the case of polyphase meters. In this field is provided a movable iron vane or armature, magnetized by a stationary coil with current in phase with the voltage of one phase of the circuit. As the iron vane is attracted or repelled by the rotating field of the current coils, it takes up a position where the zero of the rotating field occurs at the same instant as zero of its own field. Thus its position indicates the phase angle between the voltage and current of the circuit. In the three-phase meter the rotating field is produced by three coils spaced 60 degrees apart; in the two-phase meter by two coils spaced 90 degrees; in the single-phase meter the positions of the voltage and current coils are interchanged and the rotat-

ing field is produced by means of a split-phase winding connected to the voltage circuit.

The upper half of the dial indicates the power factor for lagging or leading currents when power is being delivered in one direction, and the lower half gives similar indications for power delivered in the opposite direction. In this way

Fig. 205.—Synchroscope.

the power-factor meter may serve to show a reversal of the direction of power transference. These instruments are made for single-phase, two-phase and three-phase circuits, for 25 to 60 cycles and in sizes up to 2000 volts and 2000 amperes.

614. **Illustrate and describe a synchroscope.**

The synchroscope, Fig. 205, is used in connection with the parallel operation of alternators to show the amount by which one machine may be out of phase with another and whether it is running too fast or too slow. Its mechanism is similar to that of the power-factor meter, Fig. 204, for single-phase circuits, and is arranged so that the pointer will revolve at a rate equal to the speed difference of the connected machines. By the direction of rotation of the pointer, the

synchroscope shows whether an alternator about to be connected in parallel with another already in operation is running too fast or too slow. If the speeds are the same, the pointer will show the angle of difference in phase between the machines, and when the machines are in phase the pointer will coincide with a dummy pointer painted on the disk of the instrument.

# SWITCHBOARDS

**615. What is a switchboard?**

A switchboard as employed in modern electrical station work is a strong, non-inflammable support for the controlling, indicating and protective apparatus used in connection with generators and other electrical machinery. It is, therefore, more than its name implies—a board for switching—although this name in former years was accurately suggestive of the sole purpose for which it was employed.

**616. Is a switchboard an essential part of the equipment of every electrical station?**

A small station or isolated plant containing one generator supplying current to a single circuit does not absolutely require a switchboard, although a switchboard would be of great convenience in its operation. If the station or plant contains more than one generator, or supplies more than one circuit with current, a switchboard is more than a convenience, it becomes in a practical sense a necessity. It not only simplifies the wiring of the station by providing a central point to which the conductors from the generator or generators run, and from which, through the intervention of switches, the distributing wires branch out, but it affords a convenient and safe location for the electrical measuring or indicating instruments, the controlling rheostats and the safety devices used in connection with the generator or generators. If properly designed and constructed it also protects the station building from fire risks and the station attendants from accidents.

## LOCATION

**617. What factors govern the location of a switchboard in a small station?**

In a small station there is often but one attendant to care

for the switchboard, the generator, the engine and other machinery. In such a case the relative positions of all the station apparatus should be such that each may receive the necessary attention with the greatest possible ease and safety. When the engineer is at the switchboard he should have an unobstructed view of the engines, and also should be able to see, for example, the commutators of the generators. When he is at the engines or attending to the generators he should be able to see the switchboard instruments clearly, and know fairly well where their pointers stand.

It is important to provide against accidents, but it is equally important to be prepared for prompt and proper action when a mishap does take place. In electrical plants, as well as elsewhere, troubles are liable to occur, and then the engineer, if he is alone, is needed in several places at once. It may be necessary for him to be at the engine throttle to prevent an accident, while at the same time the switchboard may demand his attention to prevent the generators from sustaining injury. For this reason it is good policy to have all the controlling devices as close together as possible, and it is particularly bad policy to have them separated by machinery of any description. It is criminal negligenee to construct a plant in such a manner that an attendant, in going from one part of his work to another, must pass dangerously near a moving belt or pulley, because when trouble arises a person has not the time to select his way carefully from one machine to another and is likely to take the shortest possible path.

**618. Give a plan of a small station and discuss the proper location of a switchboard therein, with respect to the factors just mentioned as governing it.**

Fig. 206 shows such a plan. Here *a* represents the boiler room and *b* the engine room. There are three generating sets, each consisting of an engine *d* and a generator *e;* steam is supplied by two boilers *c* and *c,* and the smoke is led to the chimney *h* through the uptake *n.* The building has been

made wide enough to provide for another set, room having been left for an engine and generator at *f*, and for a boiler at *g*.

There are several logical locations for a switchboard in this plant. One is at *k*, in line with the machines; another at *l*, at right angles to them at the nearer side of the room;

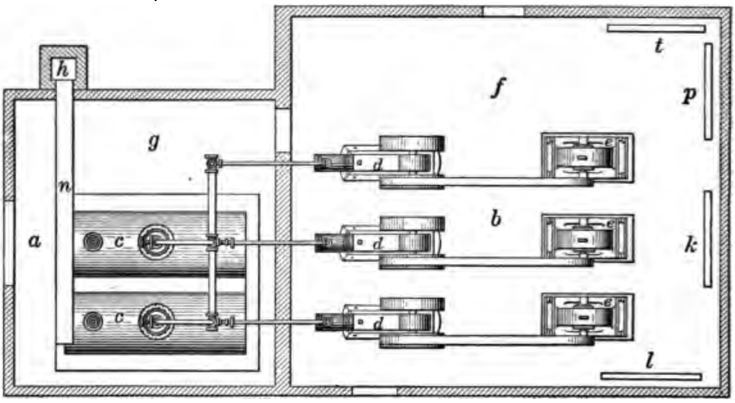



Fig. 206.—Plan of Small Electric Station, showing Logical Locations for a Switchboard.

another at *t*, similar to *l*, but on the opposite side of the room; and still another at *p*. The location *k* presents an advantage over the others as regards the nearby unobstructed view of the generators and engines from the switchboard, and of the switchboard from the machines; also as regards the ease and quickness with which the station attendant can pass from one to the other. Its disadvantage is the risk to the attendant and the switchboard, incurred by being in line with the machines and belts where the flying apart of either would endanger both life and property. This disadvantage of the location *k* is therefore sufficiently serious to overbalance its good points and eliminate it from further consideration.

The location *l*, although affording easy access to the machines and being free from the danger of flying parts, is

objectionable on account of the obstructed view of the commutators, it being seen that these parts of the generators are on the further side of the machines.

The location *t* partially obviates the disadvantage of the location *l*, but is not quite as convenient to the machines. On the whole, however, it is the best location thus far considered.

The location *p*, next to that at *k*, affords the best view of and easiest access to all the machines. It is also free from the danger of flying parts, and unless it is certain that an additional generating set will be required in the future the switchboard should be placed at this point; otherwise it should be located at *t*.

**619. Do the factors given in Answer 617 as governing the location of a switchboard in a small station apply in the case of a large station?**

No; because in a large station there are several attendants always on duty and the work of each one is confined within a limited space. In a large station the generating units are usually of the low-speed direct-connected type and not only are such machines less liable to fly apart from centrifugal force, but they are more compact and thus more easily and quickly reached. There is less objection, in stations equipped with low-speed direct-connected sets, to placing the switchboard in line with the machines than there would be in stations equipped with belt-driven generators, but owing to the large staff of employees in a large station, and the accessibility of the machines, it is rarely necessary to place it there.

In large stations the switchboard is often placed on a gallery overlooking the machinery, as in Fig. 207. This is feasible where an attendant is provided especially for the board, but obviously in a small plant such a scheme would be impracticable. The advantages of a switchboard gallery are saving in floor space; accessibility to overhead line-wires; freedom from moisture; less danger, if fire should originate at the switchboard, of its reaching adjacent combustible ma-

terial; and, in high-voltage systems, protection of station employees from serious or fatal shocks.

**620. Mention some considerations that should govern the location of a switchboard in a low-voltage station.**

In a low-voltage station the drop in pressure between the generators and the switchboard is an important matter. An

Fig. 207.—Large Electric Station where a Switchboard Gallery is Advantageous.

extreme case is that in which the current is used for electrolytic work. Here the electromotive force developed at the terminals of the machines may be but 5 volts, with an equivalent of approximately 150 amperes per horse-power. Where

ny considerable amount of power is used for this kind of 'ork, the loss in the conductors leading to and from the witchboard, which is equal to their resistance multiplied by 1e square of the current, must be kept low by locating the witchboard close to the generators. By thus shortening the ath of the current the resistance is made low and, in conse-uence, the drop in pressure, the loss in conductors and the ›st of making connections are lessened.

For ordinary low-voltage work, where there is wiring on ıe back of the switchboard, there should be four feet of ear space behind the board; a four-foot space allows suffi-ent room for a man to work without being subjected to ıe danger of making false connections with his tools, or ›ming in contact with the wires. The blowing of a fuse, r some other accident back of the board, will sometimes ause a dangerous arc which may result in serious bodily ıjury, unless there is room to get out of the way. If the 'iring is entirely on the face of the switchboard, the board ıay be placed against a brick or stone wall, although it is ıuch better to have the board set out a small distance.

**621. Should the space back of the board be closed in, or ıot?**

This space should never be closed in, except by grating or ›y wire netting, at the sides, top or bottom, as such an en-closure is liable to be used as a closet for clothing or for storage of oil-cans, or rubbish. An open space is more likely to be kept clean, and is more convenient for making repairs, examinations, etc.

**622. Is the location of a switchboard in a gallery as well adapted to an underground distributing system as to an overhead one?**

In general, conductors from the generators approach the switchboard from below, being led beneath the floor of the station from the machines to the board. The distributing conductors usually leave the board from above if the line wires are carried overhead, and from below in case of an

underground system. It follows from this that a switchboard mounted in a gallery is better adapted, as regards convenience in wiring, to an overhead distributing system than to an underground one.

**623. Mention some considerations that should govern the location of a switchboard in a high-voltage station.**

In a high-voltage station the fire hazard and the protection of the employees from electrical shocks are matters which deserve special attention. Mention has already been made in Answer 619 of the advantages of a switchboard gallery in isolating the switchboard from adjacent combustible material and in protecting the station employees. Whether the board is mounted high or low, however, a space should be left between it, the floor and the ceiling, to prevent the extension of fire which may originate on the board. Unless the floor in the vicinity of the switchboard is of concrete or other fireproof construction, as in Fig. 207, a space of at least ten inches should be allowed between the floor and the board, and there should be at least three feet between the board and the ceiling.

It is important to guard against water coming in contact with the board, for water seldom fails to cause trouble; a switchboard, therefore, ought never to be placed under or near a joint in a steam or water pipe. Automatic sprinklers and similar devices should be kept at a distance, since fire caused by electricity getting into the wrong path should not be extinguished with water. Damp air may also cause trouble, so the switchboard should not be installed near an outside door or window. It is, however, desirable to have plenty of natural light both in front and behind the board in the daytime, and provision should be made for artificially lighting these places at night.

Whereas for ordinary low-voltage work four feet is sufficient clear space to allow behind the board, from six to eight feet of clear space should be arranged for behind high-voltage switchboards.

It is well to allow for a railing around in front of the switchboard, as this is often a protection for the station employees, preventing them from coming into accidental contact with live apparatus. In high-voltage stations, where remote control is not used on the switchboard, an insulated platform in front of the board has been found effective in safeguarding the switchboard attendant.

**624. What is remote control?**

In high-voltage stations where 5000 volts and above are handled, it is not considered good practice to have high-

Fig. 208.—Switchboard equipped with Remote Control of High-Voltage Oil Switches Underneath.

voltage apparatus on the switchboard—only the measuring instruments connected to the secondaries of potential or current transformers, and the mechanical levers or electrical controlling switches. The main current-carrying switches are placed in fireproof compartments, of brick or soapstone, usually located directly behind the switchboard, if mechanical control is used, or in a gallery, basement or other convenient place, if electric or electropneumatic control is employed. This method of separating the indicating and controlling apparatus from the main current-carrying parts is called remote control. An installation of this nature is shown in

Fig. 208, where the switchboard is located in a gallery at *a*, with the transformers at the right and the high-voltage oil switches in fireproof compartments underneath the gallery at *c*.

**625. Does remote control affect the location of a switchboard?**

It does not. Especially in the case of electric or electro-pneumatic remote control the switchboard may be located anywhere in the station, regardless of the position of the main current-carrying switches.

**626. What advantages are gained by remote control?**

Minimum danger of serious electrical shocks to the switchboard attendants and a lessened fire risk to the station and its equipment.

## CONSTRUCTION

**627. What general considerations govern the construction of a switchboard?**

The construction of a switchboard depends to some extent on the position and amount of space it will occupy; different conditions call for different plans. The number of machines in a plant and their character, the number of circuits to be supplied, the different combinations to be made and the controlling devices to be used must all be considered. When it is remembered that the space allotted to each appliance may vary considerably, and that the board may be high and narrow or low and wide, it will be seen that there are not many cases exactly alike.

**628. Of what materials are switchboards made?**

Wood, slate or marble.

**629. What may be said regarding wooden switchboards?**

Wooden switchboards were formerly the only type in use, and may yet be seen in some of the smaller plants. Their construction is excusable where material for something better is unobtainable.

A wooden switchboard should be built so as to reduce the fire risk as much as possible. To meet this requirement the hardwood, skeleton form of board illustrated in Fig. 209 is best adapted. It consists of vertical posts *a*, etc., to which are fastened a number of horizontal slats *b*, etc. The dimensions of the pieces depend upon the size of the board and

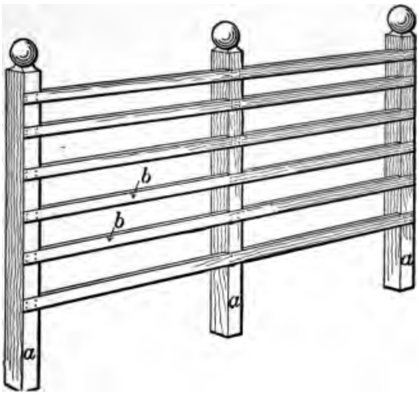



Fig. 209.—Wooden Switchboard; Skeleton Form.

the weight to be supported; they should not be too small, since lightness in this construction increases the tendency to vibrate, and vibrations tend to destroy the usefulness of the instruments. The cross-pieces may be securely fastened by placing them partly or entirely in the posts, as shown in the illustration. The distances between these pieces are governed by the lengths of the bases upon which the instruments and other switchboard apparatus are mounted. The bases should be either of slate or marble. When small snap-switches and fuse blocks are screwed on, they should have under them a piece of asbestos of sufficient width to prevent a possible arc from reaching the wood. All wires must be thoroughly insulated, and neither they nor the instruments crowded closely together.

Oak or ash is best for the ordinary type of wooden switchboards, and every piece of wood on the board should be

treated with a non-combustible paint which is also a good electrical insulator. Of late years, asbestos wood has come into use for switchboards. It is usually made into panel switchboards like marble or slate, and although costing about the same, is not as attractive as either of them, but is thoroughly fire-proof, oil-proof and moisture-proof, and has high insulation resistance and mechanical strength.

**630. What may be said regarding slate switchboards?**

Slate switchboards are extensively used for circuits not in excess of 600 volts. The slate should be black or gray and of a uniform shade; without conspicuous veins, as the veins are liable to contain mineral deposits which lower the insulation qualities of the board. Each slab should therefore be tested and not accepted unless found to be free from mineral veins. A filling should be applied to the slate in order to prevent the absorption of moisture. Manufacturers treat the slate with enamel paint, partly burning it in; the surface then becomes very hard and may be polished and grained so as to make it appear like marble or wood. If black Monson slate is obtained, simply rubbing it with oil gives it a velvety black appearance that is very attractive. Slate does not show dust or dirt as readily as other materials; it is not adversely affected by oils, nor is it easily broken. It is stronger in general than an equivalent thickness of marble, is easily cut and worked, and serves well for a low-priced switchboard designed for low voltages.

**631. What may be said regarding marble switchboards?**

Marble switchboards are used more extensively than any other kind. Marble is preferable to slate on account of its high insulating qualities. It costs more than slate, but this is not a serious disadvantage, as this item is usually a very small percentage of the total cost of a completely equipped switchboard. Marble should always be used in preference to other materials for switchboards designed to carry circuits in excess of 600 volts. White Italian marble has advantageous qualities not usually found in the American product,

and should be preferred on that account. The Eastern States' marble is more fragile and, being more porous, absorbs considerable moisture; blue Vermont marble, however, is an exception to this criticism and is extensively used for switchboard work. There are also quarries in some of the Southern States which produce marble high in insulating qualities, of fairly good appearance and easily worked. Among these are the pink and gray Tennessee marbles. When purchasing marble from a dealer the insulating qualities and the ease with which it can be worked are important points to be considered, otherwise the material may be of poor quality, or entirely useless.

**632. Is it customary to finish the marble in its natural color or not?**

On account of the liability of oil stains and dirt disfiguring a marble switchboard finished in its natural color, it is customary to put on a dull black velvety finish which will present a uniformly good appearance after long service and will not show oil spots or dirt.

**633. Must any special precautions be observed when working on marble for switchboards?**

For drilling in marble, twist drills or ordinary flat drills may be used, but they should be somewhat more pointed than ordinarily, that is, ground to an angle of about 50 degrees, instead of 60 degrees. While in use, the drill must not be allowed to choke with dust, as that will cause it to heat, which will spoil it. Such trouble can be avoided by using water in the hole; this will cause spots to appear on the marble for the time being, but in a few days the water will dry out and the spots disappear. Oil must not be used, as it spreads enormously in some marbles, a single drop having been known to spoil a whole slab as far as appearances are concerned.

**634. What may be said regarding the assembling of a small slate or marble switchboard?**

The assembling of a slate or marble switchboard is an easy matter, if it is intended for a very small plant, since then

it is only necessary to secure a single slab, of the desired dimensions, and support it upon an iron framework. From $\frac{3}{4}$- to $1\frac{1}{4}$-inch gas pipe forms an excellent iron support, and it may also be used as a wall brace for the board. In places where slate or marble may be bought for switchboard purposes, large slabs are usually obtainable, and one piece is usually sufficient for the switchboard in an isolated plant or small station.

**635. Show a small slate switchboard assembled.**

Fig. 210 shows a single-panel switchboard suitable for a single generator supplying four circuits. The panel is 4

Fig. 210.—Single Panel Slate Switchboard.

feet high and $1\frac{1}{2}$ inches thick, with $\frac{3}{8}$-inch bevel on the front edge. The supports are two pieces of $1\frac{1}{4}$-inch tubing. Castings are attached to these at suitable points and the panel is fastened to the castings by means of $\frac{1}{2}$-inch bolts. Castings are also provided on the supports for wall braces composed of the same size tubing.

**636. Show a medium-size marble switchboard assembled.**

Fig. 211 shows a seven-panel marble switchboard, each panel composed of three slabs, beveled at the edges as indicated. Like the board shown in Fig. 210, it is supported at the back by bolts passing through the slabs to a framework composed

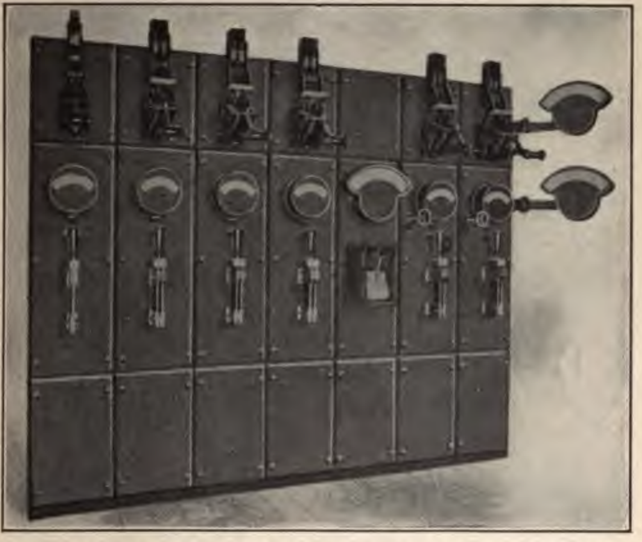


Fig. 211.—Seven-Panel Marble Switchboard; Black Finish.

of iron pipe with iron cross-pieces, floor braces, etc., attached to the vertical supports with clamps as indicated in Fig. 212. A washer is placed under the head of each bolt on the face of the board to provide sufficient bearing surface. Not all of the fittings shown in Fig. 212 are used, as this illustration is a general display of the various devices used in different forms of structural switchboard work.

**637. Should any special form of construction be used to prevent the switchboard from taking up the vibrations of the machines in the station?**

Not ordinarily, although if the switchboard must be placed

where there is much jarring and shaking, the foundation for the board should be separate from the floor.

## SWITCHBOARD FITTINGS

**638. In making connections behind a switchboard, what important points should be observed?**

Before starting to make the connections the plan of wiring should be properly laid out. The work should not be done

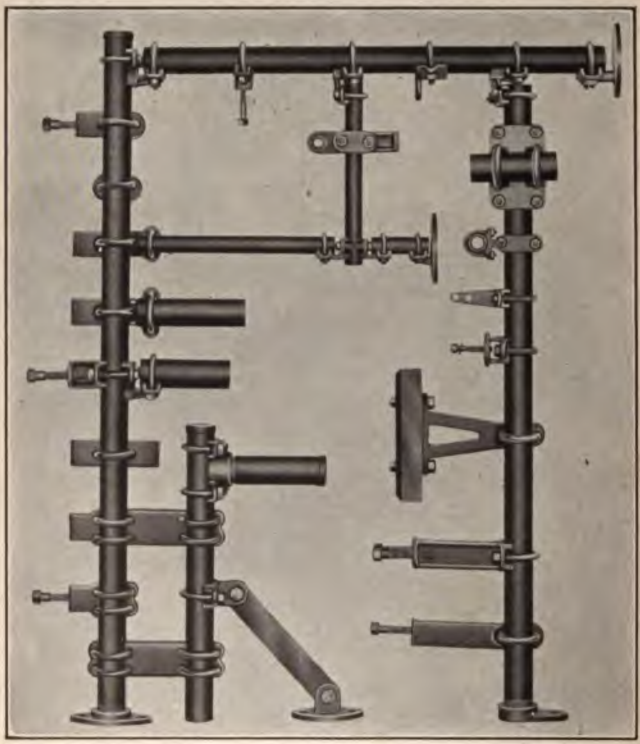


Fig. 212.—Structural Devices used in supporting Switchboard Panels.

hastily or with the expectation of going over it again. Connections behind a switchboard are too frequently neglected,

and the power lost thereby is sometimes very considerable. Could the energy thus going to waste be readily seen, the defect would soon be remedied, but to determine the loss it is necessary to use special low-reading instruments which are seldom available to the engineer. The fittings on the switchboard must therefore be carefully looked into and installed in a most efficient manner.

**639. Mention some common forms of connections used on switchboards.**

Wrapped connections, sleeve connections, V-connections.

**640. How should a wrapped connection be made?**

By placing together the two wires to be connected and wrapping them with a smaller wire. In Fig. 213 the wires

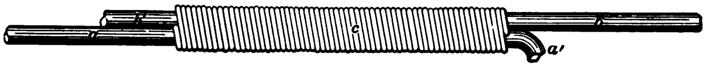



Fig. 213.—Wrapped Wire Connection.

*a* and *b* are so connected by the smaller wire *c* wrapped about them.

This is a convenient method, as no extra appliances are necessary to make a joint. It is important to see that the wires to be connected are thoroughly cleaned and trimmed, that the wrapping wire is scraped perfectly clean before the joint is made, that the wrapping is close and tight and that all of the splice is well soldered. In soldering copper, borax or sal-ammoniac should first be sprinkled over the surfaces to act as a flux in causing the solder to unite with the metal. It is seen that the end *a'* is bent outward; this may be done when there is a tendency for the wires to pull apart, but as that is not the case with switchboard connections the ends should be straight, like the end *b'*. If the length of the joint is in proportion to the diameter of the wire, and the soldering is properly done, the splice will safely stand as much strain as the wire ought ever to be called upon to bear.

**641. What is a sleeve connection?**

Fig. 214 shows such a connection. Here *c* represents a copper or brass sleeve into which the wires *a* and *b* are

Fig. 214.—Soldered Sleeve Connection.

inserted, one at each end. If the bore of the sleeve is the same as the diameter of the wires and the wires are properly soldered in, it will be impossible to pull the joint apart without first heating it. Therefore the connection is a good one electrically and mechanically; it also presents a neat appearance—a point which ought always to be remembered in switchboard work. Furthermore, it is smooth and devoid of protruding points or corners, which is of especial advantage in high-voltage installations.

**642. Are there other forms of sleeve connectors besides that shown in Fig. 214?**

Yes, another form of sleeve connector is shown at *c*, Fig. 215. The wires *a* and *b* are introduced as shown and when

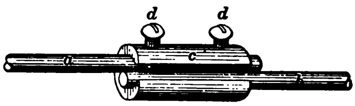



Fig. 215.—Slotted Sleeve Connection in which Solder is not Used.

side by side are clamped together by means of the screws *d* and *d*. As these screws are made of steel they may be well tightened and the union made mechanically secure; no solder is used, however, so the electrical contact is bad and this mode of connection should never be used except in emergency.

Other forms of sleeve connectors are illustrated in Fig. 216. The holes in these connectors are not slotted, but each is bored to admit a certain size of wire. A wire is inserted in each end and the two pushed toward each other until they meet

at the center of the connector, when they are made fast by means of the set-screws on top. The connectors vary in diameter and length, according to the sizes of wire.

For larger wires, set-screws made so they can be tightened

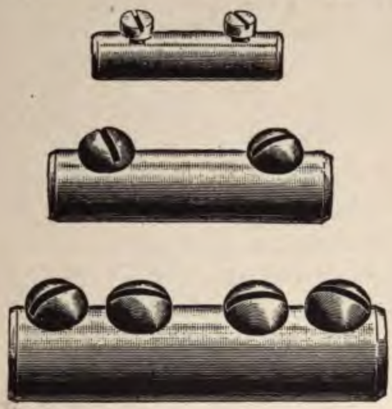


Fig. 216.—Closed Sleeve Connectors.

with a wrench, are used in the connectors. Two connectors of this type are shown in Fig. 217.

**643. How should a V-connection be made?**

A V-connection is shown in Fig. 218. It consists of a base *c* of copper or brass, to which is screwed a brass clamp *d* by

Fig. 217.—Sleeve Connectors for Large Size Wire.

means of the screws *e*, etc. A bend in the clamp and a groove in the base together form a rectangular opening into which the wire is inserted. The electrical contact is not good, but this type of connector is often used on account of the ease with which a wire may be removed or replaced.

**644. Are any other forms of switchboard connections used?**

The connections illustrated in Fig. 219 are sometimes employed. Referring to the left end of this figure, the wire *b* is bent around under the head of a bolt or screw *c;* this forms a good connection if the end of the wire is flattened

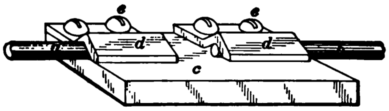



Fig. 218.—V-Connectors.

enough to allow of contact with all of one side of the washer *n*. The wire should be bent around the bolt or screw in a right-hand direction so that in the latter case the turning of the screw in tightening it will draw the wire inward rather than force it outward.

A much better connection is obtained if, instead of passing the bolt or screw through a turn in the wire, a lug *e* is

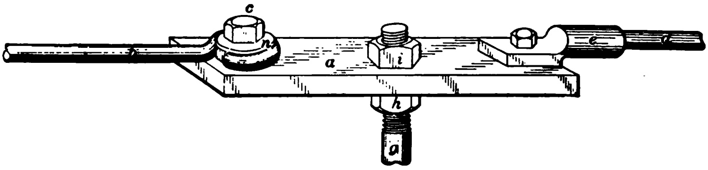



Fig. 219.—Special Forms of Connection for Electrical Conductors.

first soldered to the wire *d* and then bolted to the base *a*. The hole in the lug should be about the same size as the wire or cable with which connection is made.

A method of connecting a rod *g* to a bar *a* is also shown in Fig. 219. If the hole in the bar is smooth and the rod simply has a shoulder on the under side of the bar and a nut on top, the connection will not be good. It may be improved somewhat by providing the rod with two nuts, *i* and *h,* as illustrated. The proper way, however, is to thread the hole in the bar and screw the rod in; then when the nuts are put on tightly a good connection is secured.

**645. Are not flat copper bars sometimes used for switchboard conductors?**

Yes, they are very often used. On account of the greater ease with which connections can be made to them and their adaptability for carrying large currents, flat bars are preferable to round ones for heavy work. A thickness of one-eighth, one-quarter or one-half inch, the width being determined by the circuit-carrying capacity required, is convenient.

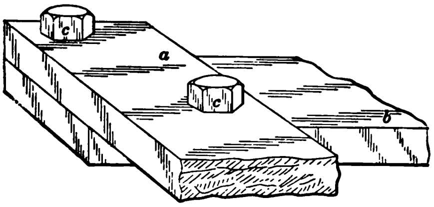



Fig. 220.—Method of connecting Bus-Bars.

**646. How should flat bars be connected together?**

As shown in Fig. 220, where the bars *a* and *b* are connected at right angles to each other by the bolts *c*, etc. The bolt holes in the bar *a* should be smooth and those in the bar *b* threaded.

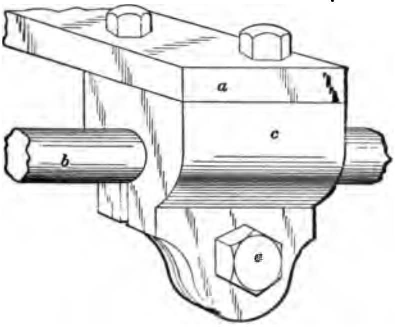



Fig. 221.—Method of connecting Bus-Bar with Round Bar Conductor.

**647. How should flat bars be connected with round bars?**

By means of a lug *c*, Fig. 221, bolted to the flat bar *a* and clamped to the round bar *b* by means of a bolt *e*. Steel bolts

should be used in electrical connections because when heated they do not expand as rapidly as copper or brass.

**648. Are tapered joints ever used in switchboard work?**

Yes, quite extensively; this form of connection being considered one of the best because the contact surfaces do not corrode or get dirty, and the connection does not easily work loose.

**649. How should a tapered joint be made?**

As illustrated in Fig. 222. The wire *a* is soldered into a lug *c* for connection with the bar *b*. One end of the lug *c* is


Fig. 222.—Tapered Joint Connection.

tapered and fits into a tapered hole in the bar *b*. By turning the screw *d*, the parts *b* and *c* are drawn together, making good contact, provided they have first been ground to fit.

**650. What method is generally used when connecting large wires or cables?**

Large wires or cables are often connected by soldering lugs

Fig. 223.—Lugs for connecting Large Wires or Cables.

to them and then bolting the lugs together, as illustrated in Fig. 223. The lugs should be bent and connected in such manner that all of the wires joined by them will be in the

same plane; this improves the general appearance of the connection.

**651. What are bus-bars?**

Bus-bars are heavy bars of copper used behind the switchboard to carry the entire current. They may be round or rectangular in cross-section, of dimensions to suit the conditions. For high-voltage switchboards, round bars are used because they are more easily insulated; they are also convenient for low-potential systems where the output is very small. When the amount of current handled is large, the cross-sectional area of the bars must necessarily be proportionally large. Heavy bars are more easily made flat than round, and as it is also less trouble to install flat bars and they make better connections, flat bars are generally used when the buses are designed for heavy service.

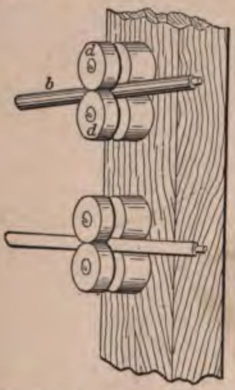



Fig. 224.—Porcelain Knobs for supporting Horizontal Conductors.

**652. How are bus-bars fastened in position behind the switchboard?**

This depends upon the position, which in turn is based upon the plan of wiring. When the bus-bars are run horizontally, as is usually the case, they are attached to the uprights of the switchboard frame. If the upright is of wood, they may be fastened by means of porcelain supports. Ordinary porce-

lain knobs are sufficient for low-potential boards, especially when the bus-bars are round and insulated. This method of supporting the wires is illustrated in Fig. 224. The grooves of the knobs *d*, etc., should fit tightly around the conductor *b*, as shown; that is, the knobs should grip the conductor or bus-bar well in order to hold it in position. Sometimes it is good practice to screw two knobs side by side below the conductor, and then center a third knob over the other two, above the conductor.

The best plan, however, is to use cleats similar to that shown in Fig. 225. A cleat consists of two parts, *a* and *b;* the part *b* is placed under the wire and next to the board, and the part *a* is placed over the wire and screwed to the

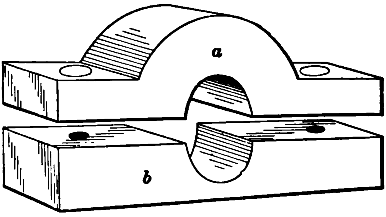



Fig. 225.—Porcelain Cleat used in Wiring.

part *b*. Cleats are made of white porcelain in all sizes; they may also be obtained in fancy designs, if desired.

**653. On high-potential switchboards should not considerable space be allowed between the bus-bars and between the bars and the board?**

On high-potential boards there should be at least six inches of space around every bus-bar; there should also be that much clearance between adjacent bars, and all of the bars should be six inches or more from the switchboard.

**654. How may round bus-bars be supported on high-potential boards?**

In order to insure the maintenance of proper distance between the bars and the board, brackets may be employed, as in Fig. 226. The supporting arm *a* of the bracket is fastened

to the board *b* by means of bolts *c*, etc. The insulator consists of two parts, *f* and *f*, clamped to the bus-bar *g* by means of the upper half of the bracket *d*, which is fastened down

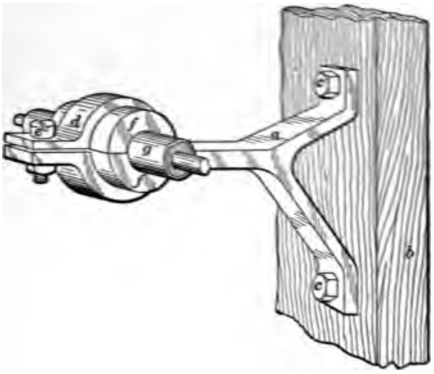


Fig. 226.—Bracket for supporting High-Potential Conductor.

with two screws *e*, one of which is shown. The insulator *f f* may be in one piece, in which case it should be of such diameter as not to fit too loosely around the insulation *g*.

**655. Are the methods of making connections which have already been explained applicable to the different forms of bus-bars?**

Yes, if the contact surfaces are sufficient in area to provide against loss at the connections and the quality of the connectors and conductors is good.

**656. How much current is it considered safe to transmit per square inch of contact surface?**

Between 100 and 200 amperes per square inch, depending upon the method of clamping, bolting or soldering. A good average working value is 160 amperes per square inch of contact surface. Minor connections to bus-bars, such as those of switch leads, feeder ends, etc., whether bolted, clamped or soldered to the bars, should have a contact surface of between ten and twenty times the cross-sectional area of the smaller of the two conductors connected.

**657. How much current is it considered safe to transmit through copper conductors per square inch of their cross-sectional area?**

Up to 3000 amperes, it is safe to allow 1000 amperes for every square inch of cross-sectional area. And, as 1,000,000 circular mils is approximately equal to 1 square inch, according to Answer 59, we may allow 1,000,000 circular mils for 1000 amperes, or 1000 circular mils per ampere.

**658. Are there any special conditions under which the figures given in Answer 657 would not be safe?**

Yes; for example, if the quality of the copper conductor is not good. Two copper bars may be of the same dimensions and apparently just alike, but still have widely different current-carrying capacity. Only a small amount of foreign material added to copper greatly depreciates its value as an electrical conductor. By merely adding 1.56 per cent. of zinc to a copper conductor, the current-carrying capacity is reduced to 46.88 per cent. of the carrying capacity of pure copper; 5.51 per cent. of zinc added, reduces the conductivity to 33.32 per cent. of that of pure copper. The loss in conductivity caused by the addition of 1.41 per cent. of tin is 37.54 per cent., and this loss is increased to 80.32 per cent. by increasing the percentage of tin to 6.02. Therefore, unless an engineer measures the resistance of the bars, he cannot judge accurately of their actual conditions, and if he has reason to suspect the quality is not good, he should assure himself on the point by actual measurements and check up the results with the table on pages 20 and 21.

The current-carrying capacity is also affected by conditions other than the quality of the copper, most important of which is the amount of surface exposed to the atmosphere. The resistance of copper increases rapidly as the temperature rises, but the temperature may be kept down to some extent by providing ample surface for radiation. Thus, a ½ by 2-inch bar of copper will be more efficient than a 1 by 1-inch bar, although the cross-sectional areas are the same. For this

reason it is best to use several small bars in place of a single heavy bar having a cross-sectional area equal to that of all the small ones, for carrying current in excess of 3000 amperes. The current-carrying capacities in the table, pages 20 and 21, apply only to bus-bars and other plain copper conductors. In switches, etc., the current-carrying capacity is limited by the temperature rise, as explained in Answer 682.

**659. Explain how the weight of copper on a switchboard may be calculated?**

Copper weighs 0.3204 pound per cubic inch. Multiplying this figure by the number of cubic inches in a bar will give its total weight. Applying this method to the other switchboard fittings made of copper and adding the results together will give the total weight of copper on the switchboard.

**660. How may the expense of the copper fittings on a switchboard be approximately estimated?**

Bus-bars and other plain straight copper pieces usually cost about 22 cents per pound. Angular copper fittings cost about 50 cents per pound. Multiplying these figures by the respective weights of plain and angular copper fittings used and adding the products together will give an idea of the approximate cost.

## ARC-LIGHT SWITCHBOARDS

**661. What is an arc-light switchboard?**

A switchboard designed for the connection of series arc-light circuits to the source of supply.

**662. Is this type of switchboard constructed differently from the switchboards previously illustrated and described?**

Yes; owing to the greater flexibility required in series arc lighting, any arrangement of switches for making the transfers mentioned in Answer 661 would be exceedingly complicated. The various connections are therefore made by inserting plugs into sockets or receptacles, the circuits being completed in some boards by flexible cables and in others by the plug itself.

**663. Which of the two methods of completing the circuits is preferable?**

That in which the connections are made by using plugs without cables, because there is no danger to the attendant from accidental contact with exposed or poorly insulated cables carrying high-voltage currents, and because where a large number of generators and circuits are operated, the front of the board is not cluttered up with cables.

**664. Is there not liability to currents arcing between the plug and receptacles when withdrawing the plug to disconnect a circuit?**

No; because the circuit to be cut out is first short-circuited. On account of the automatic regulation of constant-current

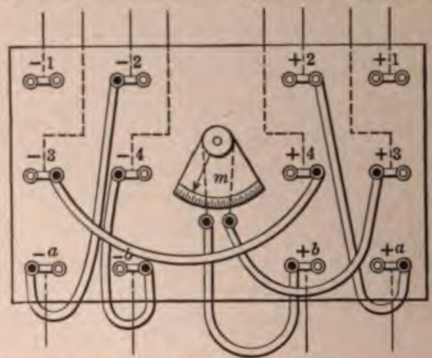



Fig. 227.—Arc-Light Switchboard where Connections are made by Plugs and Cables.

transformers (see Answer 463) used in connection with series arc-lighting systems, the short-circuiting of the lamps causes the voltage of the lamp circuit to drop almost to nothing.

**665. Illustrate and describe an arc-light switchboard in which the connections are made by using plugs with cables.**

Fig. 227 shows a simple board of this kind designed for two feeder circuits, *a* and *b*, and four line circuits, *1*, *2*, *3* and *4*. The positive (+) and negative (—) terminals of each feeder circuit are wired to separate receptacles which are

in duplicate as indicated in the bottom row. The positive and negative terminals of each line circuit are likewise wired to duplicate receptacles as indicated in the two upper rows. Each terminal is thus made double so that transfers may be made without opening the circuit. An ammeter *m* is mounted on the board for measuring the strength of the current in any of the circuits.

**666. Describe the effect of the connections shown on the board in Fig. 227.**

The feeder circuit *a* is connected to line circuit No. 2, while the feeder circuit *b* is connected to line circuits Nos. 3 and 4,

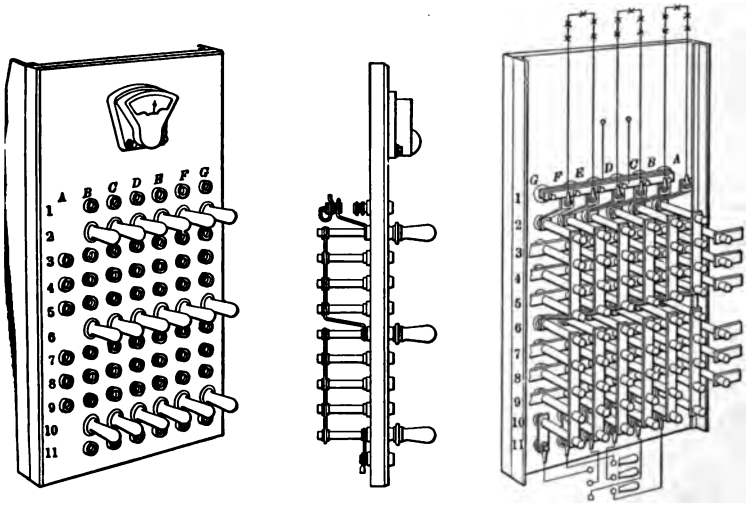


Fig. 228.—Arc-Light Switchboard where Connections are made by Plugs without Cables.

which are connected in series. The ammeter *m* is connected in circuit with the feeder circuit *b*.

**667. Illustrate and describe an arc-light switchboard in which the connections are made by using plugs without cables.**

Fig. 228 shows a switchboard of this kind, having provision for three feeder circuits and three line circuits. In order

to indicate clearly the various combinations, the vertical rows of receptacles are lettered and the horizontal rows are numbered. The ends of the vertical bars are connected respectively to the line and feeder circuits. Each of the bars is broken in three places, and a machine may be connected to its circuit by plugging across the breaks (the illustration shows each line circuit on its own feeder circuit), thus making the bar continuous; by removing any pair of plugs the corresponding line circuit is disconnected. The sockets in row *1* are ammeter "jacks" and are used in connection with a special plug for connecting the ammeter in any circuit.

The six horizontal bars are for the purpose of transferring a feeder circuit to some line circuit other than its own. Each horizontal bar is provided, at the left-hand side of the panel, with a receptacle (*A-3, A-4, A-5, A-7, A-8* and *A-9*) by means of which it can be connected with the horizontal bar on an adjoining panel. All ordinary combinations can be made by means of the bars and plugs, but cable plugs are provided with each panel, so that when necessary, machines and feeders can be transferred without the use of the bars. These plugs and cables are intended for use only in case of emergency, and are used in the receptacles in the horizontal rows *2* and *11*.

**668. Of what material are arc-light switchboards made?**

Marble is generally used. Slate is not a good material on account of its liability to contain metallic veins. Owing to the high potentials common to series arc-light circuits, special care is necessary in insulating them.

**669. Show and explain more in detail the construction of the plugs in Fig. 228 and of the sockets or receptacles for them.**

Each plug, Fig. 229, consists of a long copper bar *a* fitted tightly into a hardwood handle *h*. All the receptacles, or plug switches as they are sometimes called, are of the type shown in Fig. 230. The marble board is not relied upon entirely for insulation; each receptacle is insulated from the board by porcelain bushings as shown at *a* and *a*. These

bushings not only insulate the bus-bar *n* in each row from the panel, but prevent the attendant from coming in contact

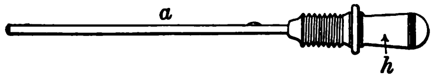



Fig. 229.—Plug Used in connecting Circuits on Arc-Light Switchboard.

with it. The rear bus-bar is shown in Fig. 230 at *m*, with a contact thimble at *c* and a terminal at *e*. The fiber tube *s* serves as a guide for the plug when inserted.

In order to distinguish between the various receptacles on the face of the board, bushings of different colors are used.

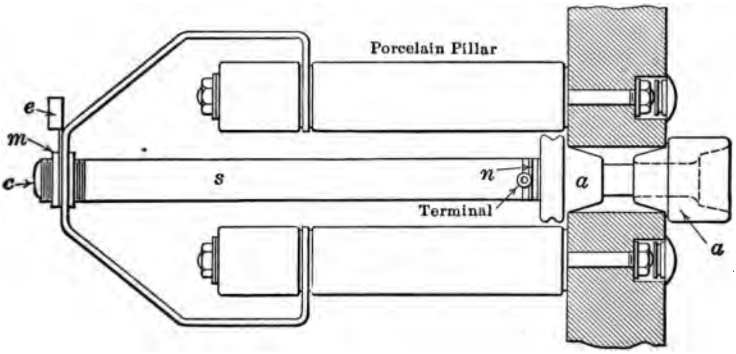



Fig. 230.—Plug Switch in Arc-Light Switchboard.

All open-circuiting, bus-connecting, cable-transfer and ammeter-jack receptacles have brown porcelain bushings, and all bus-transfer receptacles have blue porcelain bushings.

**670. How does the one ammeter shown in Fig. 228 serve for so many circuits?**

An ammeter jack, Fig. 231, enables this to be done without inconvenience. Two of these jacks are provided for each circuit, and one ammeter jack plug, Fig. 232, is used for all of them. By inserting this plug in any ammeter jack the ammeter is thrown in series with that circuit. In removing the plug the circuit is closed around the ammeter at the instant that the plug is removed.

Ammeter jacks are included in both sides of each circuit to facilitate testing for grounds. A leakage, or flow of current to ground will show a different reading when the ammeter is plugged into the different sides of the circuit.

## SWITCHES

**671. What is a switch?**

A device for opening and closing a circuit, or for shifting a current from one circuit to another. It may be either a

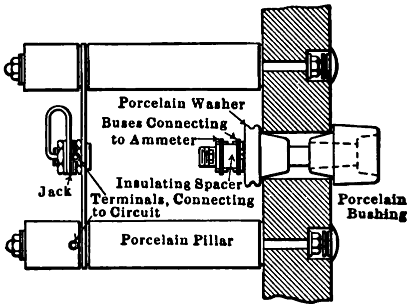



Fig. 231.—Ammeter Jack on Switchboard in Fig. 228.

knife switch, in which the circuit is opened or closed by means of one or more blades, or it may be a snap switch that opens or closes the circuit by means of a quick rotary motion of the contact part through the action of a spiral spring. The latter

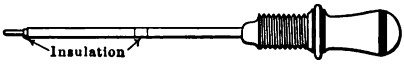



Fig. 232.—Plug used in Ammeter Jack, Fig. 231.

kind is used mostly in connection with electric incandescent lamps.

**672. What kind of switches are generally used on switchboards?**

The kind known as knife switches, a simple form of which is shown in Fig. 233. The knife switch derives its name from the knife-blade-like shape of its connecting part *a,* called the

blade. The parts which receive the blade when the switch is closed are shown at *c* and *d;* they are called the jaws or clips, and are mounted in the bars or strips *e* and *s*, which in turn are mounted on the insulated base *b*.

The terminals of the circuit to be opened or closed by means of the switch are connected to the plates *e* and *s* by the bolts *r* and *v*. The plates *e* and *s* are called the terminals of the switch, or sometimes the jaw or clip bases. The blade *a* is hinged at one end to the post *o*, and is provided with an insulating handle *g* at the other end.

With the blade in the position shown in the figure, there is

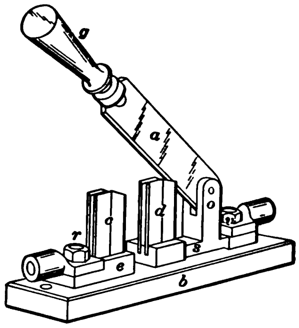



Fig. 233.—Single-Pole Single-Throw Switch.

no connection between the jaws *c* and *d*, and the switch is said to be "open." By pressing down the handle *g*, the blade *a* is forced into both jaws, *c* and *d*, electrically connecting them together; the switch is then said to be "closed."

**673. Of what materials are the different parts of a switch, such as shown in Fig. 233, made?**

The jaws, plates and blade are usually made of copper, although the bars are sometimes made of brass. The base is either marble or slate; the bolts are steel or copper, according to conditions, and the handle is of rubber, wood or fiber. When a knife switch is mounted on a slate or marble switchboard it is not provided with the base *b;* the bolts *r* and *v*, from the switch terminals, pass through the switchboard panel

and connect with the circuit terminals on the back side of the board.

A switch with one blade is called "single-pole," and when there are two blades it is called "double-pole." In like manner there are "three-pole" and "four-pole" switches used in electrical work.

**674. Are the switches used on high-potential circuits made like the one in Fig. 233?**

No; switches for use on high-potential circuits must open quickly when pulled, so as to prevent arcing between the blades and the jaws with which they have been in contact. Otherwise heavy arcs would form and burn the copper composing the blades and jaws. To prevent this, quick-break switches have been devised.

**675. Illustrate and describe a quick-break switch.**

Fig. 234 shows a double-pole switch of this type. The blades are shown at *a* and *d*, and the arms at *c* and *e*, the

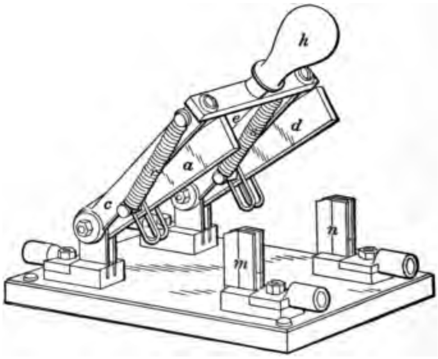



Fig. 234.—Double-Pole Single-Throw Quick-Break Switch.

latter carrying the handle *h*; both the arms and the blades are pivoted at the same point. When the switch is to be opened, the handle *h* is raised, and the arms *c* and *e* necessarily follow. The blades *a* and *d*, however, remain in contact with the jaws *m* and *n* until the handle is raised sufficiently to

exert the necessary tension on the springs *r* and *s*, the extremities of which are fastened to the arms and blades of the switch. When the tension of these springs becomes sufficient, the blades are pulled away from the jaws *m* and *n* with great force, and therefore quickly break the circuit and prevent serious arcing.

**676. Do quick-break switches of the kind described in Answer 675 possess any serious disadvantages?**

They are not very desirable for use on inductive circuits, such as those containing generators and motors, owing to the fact that when the duration of the arc is thus shortened a strain is produced upon the insulation of the machines which is liable to be of a serious nature. When a live inductive circuit is opened, the current tends to keep on flowing, and if the flow is checked very suddenly at the switch the current tries to complete a circuit through some other path. In attempting to do this the current is liable to break through the insulation where it is not at its best and seriously damage it. For opening inductive circuits carrying pressures above 1000 volts, the quick-break switches of the kind previously considered are inadequate. On non-inductive circuits of small power, however, they may be used up to 2500 volts if properly designed.

**677. How may the disadvantages of quick-break switches, mentioned in Answer 676, be overcome?**

To overcome the kick or reactive effect of the current and at the same time protect the switch from being burned by prolonged arcing of the current between the contact parts, two sets of contacts may be provided, one set of copper and the other set of carbon blocks. When a switch of this kind is closed, the copper contacts serve to conduct the current with the least resistance possible; when the switch is opened the copper contacts separate first, forcing the entire current through the carbon blocks so that when these separate an instant later, the current has been considerably reduced by

their higher resistance and whatever arcing occurs takes place between the carbons and does no harm to the copper parts.

**678. Are knife switches made in any other forms than those just described?**

Yes; there are "double-throw" knife switches with different number of blades in common use.

**679. Show a single-pole double-throw switch.**

Fig. 235 illustrates this type. This switch corresponds to the one in Fig. 233 because it is of single-pole construction.

Fig. 235.—Single-Pole Double-Throw Switch.

**680. Are there also double-throw double-pole knife switches?**

Yes; two switches of this type are shown in Figs. 236 and 237. The former has two sets of jaws and is known as a single-break switch; the latter has four sets of jaws and is

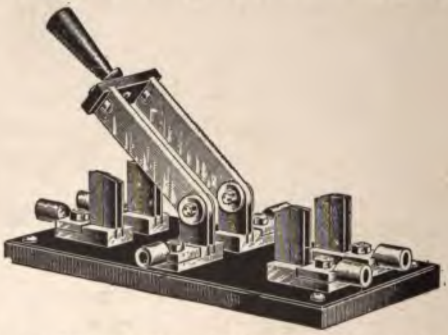


Fig. 236.—Double-Pole Double-Throw Single-Break Switch.

known as a double-break switch. The switch with four sets is preferable in all cases, and it is always used for carrying heavy currents.

**681. Show a knife switch made with three blades or poles.**

A three-pole single-throw knife switch is shown in Fig. 238; a double-throw knife switch of the same construction is shown in Fig. 239.

Fig. 237.—Double-Pole Double-Throw Double-Break Switch.

**682. What important considerations enter into the construction of switches for electrical work?**

The current-carrying parts should have a sufficient cross-section that the heating effect of their full-load current does

Fig. 238.—Three-Pole Single-Throw Switch.

not increase their temperature more than 50 degrees Fahrenheit (28 degrees Centigrade) above that of the surroun-

ing air. The surfaces of the contact parts should have an area of about one square inch per 100 amperes, or approximately ten times the cross-sectional area. If, however, the mechanical pressure between the contact surfaces be greater than that usually employed, the area of the contact surfaces may be less, and if the pressure be less than usually employed, the area of the contact surfaces must be greater than would be used for normal pressure. The blades, jaws and contacts should have ample metal for stiffness and be constructed to give an even pressure throughout, but no part of the contact surfaces should grind, cut or bind when the blade is

Fig. 239.—Three-Pole Double-Throw Switch.

removed. The workmanship should be such that the blades can be moved with a perfectly uniform motion, and the jaws should be so alined that the blades will enter them without the slightest stoppage.

**683. What kind of switches are used for very high-potential circuits?**

For opening inductive circuits carrying pressures above 1000 volts, switches are made in which the break takes place in oil. In others, the arc is ruptured in open air by drawing it through a wide break, and in still others, the arc is ruptured by a sliding shutter which intercepts the arc when the contact is broken.

**684. Illustrate and describe an oil switch for a high-tension circuit.**

A three-pole oil switch for a 15,000-volt 300-ampere alternating-current circuit is shown in Fig. 240. This switch is designed for remote control by means of a system of levers as shown in Fig. 241 where the oil switch is located at *o*, the


Fig. 240.—Three-Pole Hand-Operated Oil Switch.

levers at *c*, etc., and the control handle at *h* on the switchboard panel *m*.

The copper blades of the switch are shown in Fig. 240 at *c*, *e* and *v*; the stationary contacts at *b*, *d*, etc., consisting of flared fingers of copper, two fingers in each set being extended to take any arcing that may occur, and the oil tank at *t* divided into separate compartments for each set of poles. The switch is opened by pulling out the control handle at the face of the

switchboard. This movement, through the system of levers and bell-cranks shown in Fig. 241, lowers the part *c e v* in the three tanks and thus separates the contacts in each of the three parts of the circuit at two points simultaneously.

When the contacts separate, the arcing across them is very small because the oil is an excellent insulator, and being liquid it immediately fills the space between the contacts and stops the passage of the current. Owing to the circuits being opened at several points simultaneously, the electromotive force per

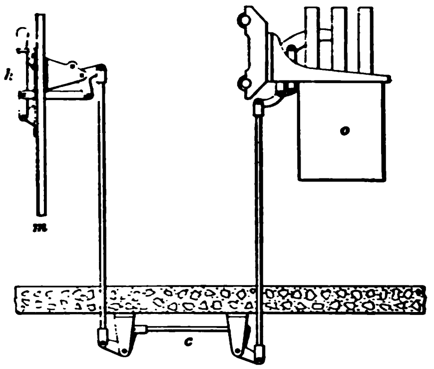



Fig. 241.—Arrangement of Levers for Remote Control of Hand-Operated Oil Switch in Fig. 240.

break is considerably less than the total electromotive force of the circuit, and this shortens the spark and its duration so that the burning effect upon the contacts is very slight.

**685. Are all oil switches operated by hand?**

No; some are operated by electricity and others by compressed air.

**686. Show an electrically operated oil switch.**

A three-pole electrically-operated oil switch for a 13,000-volt 500-ampere alternating-current circuit is shown in Fig. 242. The motor, at *C*, is a small 110-volt direct-current machine. The leads from it run to the controlling switch on the switchboard. The terminals *s*, *s*, *s*, of the oil switches project downward through the bottom slab *n* of the switch cells.

There are two sets of contacts, the main ones being the laminated copper brushes at *c*, etc., which make contact with metal bosses at *e*, etc., on top of the oil vessels *v*, etc., when the switch closes. The secondary contacts are the movable brass rods *r*, etc., which enter hollow cylinders consisting of vertical segments held together by helical springs. The rods are

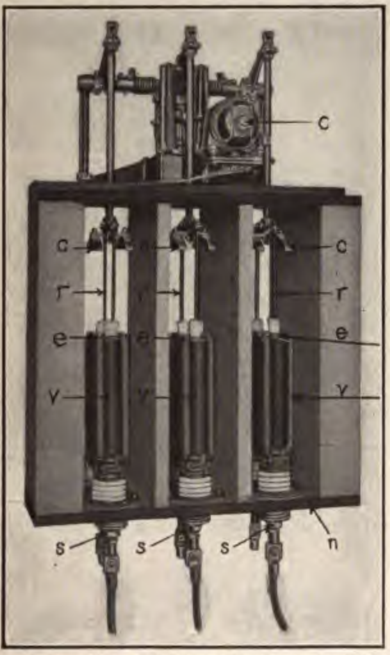



Fig. 242.—Three-Pole Electrically-Operated Oil Switch.

rounded at the lower end and the cylinders are bell mouthed. The secondary contacts are within the oil cylinders *v*, which are composed of steel.

## PROTECTIVE APPARATUS

**687. What kinds of protective apparatus are generally used?**

Fuses, plug cut-outs, circuit breakers, lightning arresters and choke coils.

**688. What is a fuse?**

A fuse is a strip or wire of fusible alloy composed of tin, lead and bismuth. It is inserted in series with a circuit at some convenient point and is made of such size that it will melt and thus open the circuit when the current exceeds the allowable amount for the size of wire used as given in the table on pages 20 and 21. Fuses are made in two general forms: exposed, or "open"; and "enclosed."

**689. Show some fuses of the open type.**

Fig. 243 shows an open fuse made of flat strip or ribbon. The strip *c e* is composed of the fusible alloy, and is shown

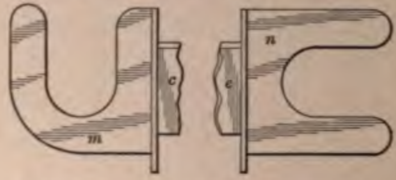



Fig. 243.—Ribbon-Type Open Fuse.

broken in the illustration to save space. It is soldered to the copper contact pieces *m* and *n* to facilitate its connection in circuit. An open fuse of wire is shown in Fig. 244. The


Fig. 244.—Wire-Type Open Fuse.

fuse wire *a s* is of the same composition as the strip *c e*, Fig. 243, and is soldered to the contact strips *b d* as in the previous case. The wire form of fuse is generally used for protecting circuits which carry currents up to and including 30 amperes. Up to 5 amperes rating, the fuse wire should be at least 1½ inches long; for each increment of 5 amperes ½ inch should be added. The ribbon form exceeding 4 inches in length is usual for circuits carrying currents above 30 amperes.

**690. Describe the method of mounting these fuses for connection in circuit.**

A slate or marble fuse block *f*, Fig. 245, is generally employed. This is provided with copper terminal blocks *c* and *d*, to which the wires of the circuit are connected. If the circuit in which the fuse is to be introduced carries over 30 amperes, the connection is preferably made by means of copper lugs *a* and *b* soldered to the wires and the lugs screwed to the terminal blocks *c* and *d* as indicated.

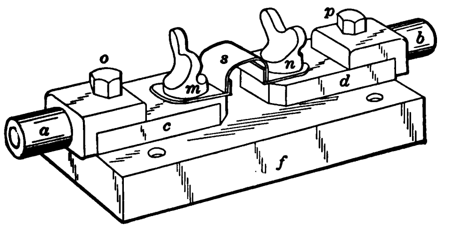



Fig. 245.—Open Fuse Block.

**691. Explain how the fuse in Fig. 245 protects the circuit.**

The fuse *s*, when connected across the gap between *c* and *d* by means of the thumb-screws *m* and *n*, allows the normal current to pass through the circuit as before. As the current-carrying capacity of the fuse is limited, however, it being made to conduct not over a certain number of amperes, the fuse will become hot and melt if the current exceeds that specified amount, and by melting open the circuit.

**692. What indicates the current-carrying capacity of a fuse?**

Each fuse is stamped with about 80 per cent. of the maximum current which it can carry indefinitely; this allows about 25 per cent. overload before the fuse melts, or, as it is sometimes stated, blows. With open fuses of ordinary shapes and with not over 500 amperes capacity, the minimum current which will melt them in about five minutes may be safely taken as the melting point, as the fuse practically reaches its

maximum temperature in this time. With larger fuses a— a longer time is necessary. This datum is given to facilitate —e testing.

**693. Describe the construction of an enclosed fuse.**

Referring to Fig. 246, which shows a lengthwise sectional view through an enclosed fuse of approved type for a 250-

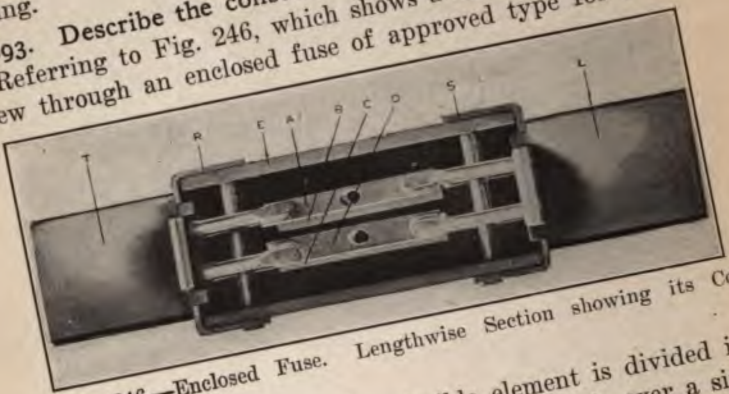



Fig. 246.—Enclosed Fuse. Lengthwise Section showing its Construction.

volt, 400-ampere circuit, the fusible element is divided into strips *A*, *B*, *C* and *D*. The advantage of this over a single strip is the formation of a number of small arcs instead of one large arc when the fuse blows and consequently the quicker absorption of the metal vapor. The strips are surrounded by a granular material which serves to smother the

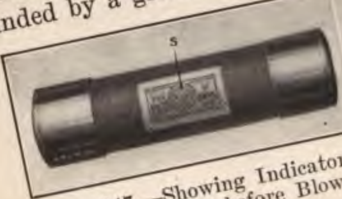



Fig. 247.—Showing Indicator on Enclosed Fuse before Blowing.


Fig. 248.—Showing Indicator on Enclosed Fuse after Blowing.

arcs and the whole is enclosed in a fiber tube *E*, provided w metal end caps *R* and *S*, to which the extremities of the f strips and the contact blades *T* and *L* are connected.

**694. Since the fusible element is not visible in the closing tube, how may a blown fuse be detected?**

An indicating label shown at *s* in Figs. 247 and 248 i

vided for this purpose. Its operation depends upon a fine German silver wire, the ends of which are connected with the inner surface of the two end caps, and midway between them passes through a special compound on the inner gummed side of the indicating label. Where the fuse operates, an abnormal current is forced through the German silver wire and the resulting heat ignites the compound so that it discolors the label as shown at *s* in Fig. 248. Comparing Fig. 247 with Fig. 248, the former of which shows the appearance of the label before the fuse is blown, and the latter which shows it afterward, it is seen how easy a blown fuse may be detected.

**695. How is the enclosed type of fuse arranged for connection in circuit?**

Figs. 249 and 250 illustrate the two usual methods of connecting enclosed fuses in circuit, the former showing what

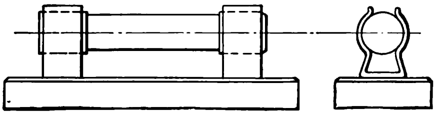


Fig. 249.—Enclosed Fuse with Ferrule Contact.

is generally known as a ferrule contact and the latter a knife-blade contact. The ferrule contact is recommended for circuits carrying current up to 60 amperes, and the knife-blade contact for circuits carrying current between 60 and 600 amperes.

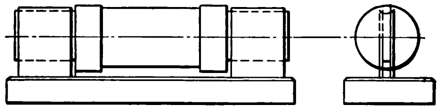


Fig. 250.—Enclosed Fuse with Knife-Blade Contact.

**696. Are enclosed fuses considered preferable to the open type?**

They are preferable, because in operation the heated metal cannot fly out and set fire or cause trouble elsewhere. Because of their lower fire risk they are now used largely in place

of the open type; which latter are permissible only in cabinets, on panel boards, etc.

**697. Are fuses made the same for use on both direct- and alternating-current circuits?**

Yes; all that has been previously stated concerning fuses applies to both cases.

**698. What is a plug cut-out?**

The plug cut-out is a compact, safe, neat and simple device for fusing a circuit. Fig. 251 shows at *A* and *B* the two parts


A B

Fig. 251.—Plug Cut-Out.

comprising a plug cut-out. The part *A* is the base. It is made of porcelain and carries a screw socket *c*, constructed similarly to an incandescent lamp socket; the metal bottom is connected to the terminal *e*; and the metal side, which is insulated from the bottom, is connected to the terminal *s*.

The part *B* is the plug. This also is made of porcelain, and inside it, connected between the metal screw threads *r* and the metal tip *i*, is a fuse wire. Consequently, when the plug is screwed into the socket *c* of the base, the terminals of the circuit in which the base is connected are joined by the fuse wire in the plug.

**699. Is there any other form of plug cut-out besides that shown in Fig. 251?**

Yes; for very high voltages the one shown in Fig. 252 is used.

**700. Describe the plug cut-out in Fig. 252.**

The cone or cap *a* is made of glazed porcelain and is open only at the bottom. It is provided with two jaws *c* and *d*,

which receive the porcelain blades *m* and *n* on the plug shown at *b*. The fuse *s* extends around the end of the plug and passes through a small tube *v*, on each side. This arrangement prevents any arcing across the terminals of the plug. One terminal is shown at *o*. Contact between the terminals of the plug and the circuit wires *x* and *z* is made by inserting the plug in the cap *a* from underneath and giving it a quarter turn. The plug is shown removed, but when in its place all the terminals are entirely boxed up by the porcelain


Fig. 252.—Plug Cut-Out for High-Voltage Circuits.

cap. This part of the circuit is, therefore, closed, and if a current should melt the fuse and happen to arc across the terminals of the plug, it will be confined and no damage will be done.

**701. Are fuses considered a satisfactory protection from abnormally high currents of short duration?**

The fuse operates by reason of the heat developed by the current, so that a heavy current of short duration might not fuse the wire because it requires some time to heat. For

the instant and accurate opening of a circuit under these conditions a circuit breaker is recommended.

**702. What is a circuit breaker?**

A circuit breaker is a switch arranged to open automatically when the current becomes excessive. It is connected in circuit and makes contact in nearly the same manner as an ordinary knife switch, but differs therefrom in the manner of opening the circuit. The knife switch has to be pulled open by hand, but the circuit breaker is opened by a spring when the current exceeds a certain strength. The magnetic

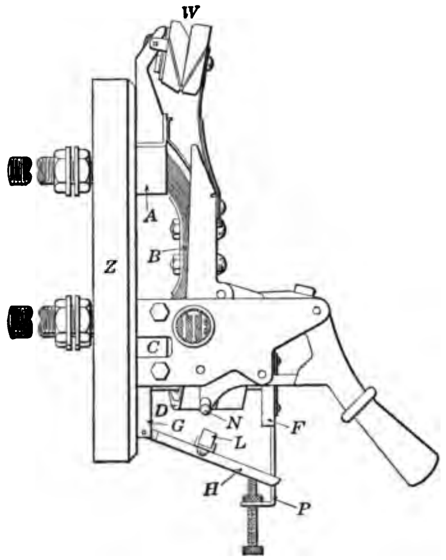



Fig. 253.—Double-Pole Circuit Breaker; Side View.

effect of the current itself is generally used to accomplish this. The circuit breaker is held closed by a latch, and when set to open at the desired number of amperes, this current in flowing through the circuit causes an electromagnet to operate a trip which releases the latch and allows the spring to open the circuit breaker.

**703. Explain the principle of operation of a circuit breaker with reference to a modern type.**

Referring to Figs. 253 and 254, which show, respectively, side and front views of a double-pole circuit breaker mounted on a slate base *Z*, with the terminals *A* and *E* projecting through to the back. The current from the generator enters the circuit breaker at *A*, and when the breaker is closed as indicated in the illustrations, passes through the laminated copper bridge *B* to the contact block *C;* thence through the electromagnet coil *D*, and out through the terminal *E*. Returning from the other side of the line, it enters at *I*, passes

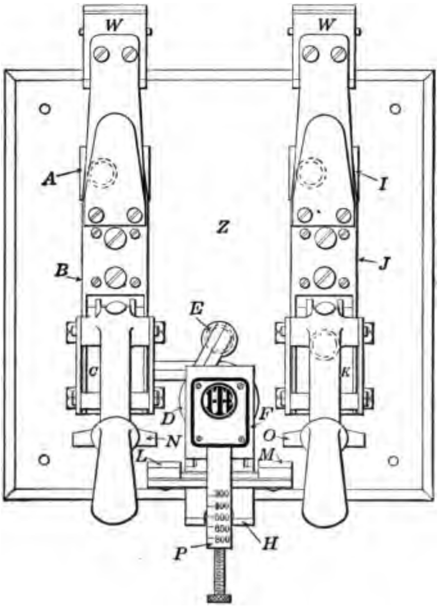



Fig. 254.—Double-Pole Circuit Breaker; Front View.

through the laminated copper bridge *J* to the terminal *K*, whence it passes out and back to the generator.

The electromagnet coil *D* has an iron core with pole pieces *F* and *G*, and these, when current passes through *D*, tend to attract and lift the armature *H* up from the screw on which

it normally rests. If this screw be properly adjusted vertically in accordance with the calibration plate *P*, to the number of amperes at which the breaker is to operate and open the circuit, then when this amount of current flows through the electromagnet coil the armature will be drawn up and the insulated projections *L* and *M* on it will strike against the respective latches *N* and *O*, thereby releasing the two switch arms *B* and *J*, which instantly open or fly backward in response to the force supplied by springs provided for the purpose, and open the circuit at two points. To obviate objectionable burning of the copper contacts upon the opening of the circuit, the arc is finally broken on the refractory carbon blocks *W* at the top of the circuit breaker.

**704. Show the construction of another modern type of circuit breaker and point out the principal parts.**

Fig. 255 shows the general construction of a circuit breaker, with reference letters on the principal parts to which the following explanations apply:

| | |
|---|---|
| A | Spring for the Carbon Block forming Secondary Contact |
| B | Contact Plate of the Burning Tips |
| C | Screw for D and R |
| D | Spring of the Burning Contact Tips |
| E | Insulating Cover for Trip Magnet Frame |
| F | Capscrew for E |
| G | Capscrew for A |
| H | Support for Main Laminated Copper Brush |
| I | Handle Lever |
| J | (Lower) Contact Stud |
| K | Tripping Catch for Opening Circuit Breaker by Hand |
| L | Catch |
| M | Laminated Connection |
| N | Washer for O and I |
| O | Handle for Closing Circuit Breaker |
| P | Calibrating Tube |
| Q | Carbon Arcing Block |
| R | Burning Contact Tip |
| S | Screw for B |
| T | Contact Stud (upper) |
| U | Laminated Copper Brush |
| V | Washer for F |
| W | Trip Magnet Frame |
| X | Trip Coil—the Electromagnet which automatically opens the Circuit Breaker under Abnormal Current |
| Y | Main Link |
| Z | Pin for Y |
| Aa | Cotter Pin for Z |
| Ba | Magnet Frame |
| Ca | Clamping Plate |
| Da | Pin for K |
| Ea | Pin for H and Ba |
| Fa | Laminated Connection |
| Ga | Base |
| Ha | Calibrating Screw by means of which the Circuit Breaker is set to operate at the desired number of Amperes. |

**705. Explain how the different sets of contacts in the circuit breaker shown in Fig. 255 operate during the opening process.**

Referring to Fig. 256, *A* shows all the contacts closed,—the condition prevailing when the circuit breaker is closed and

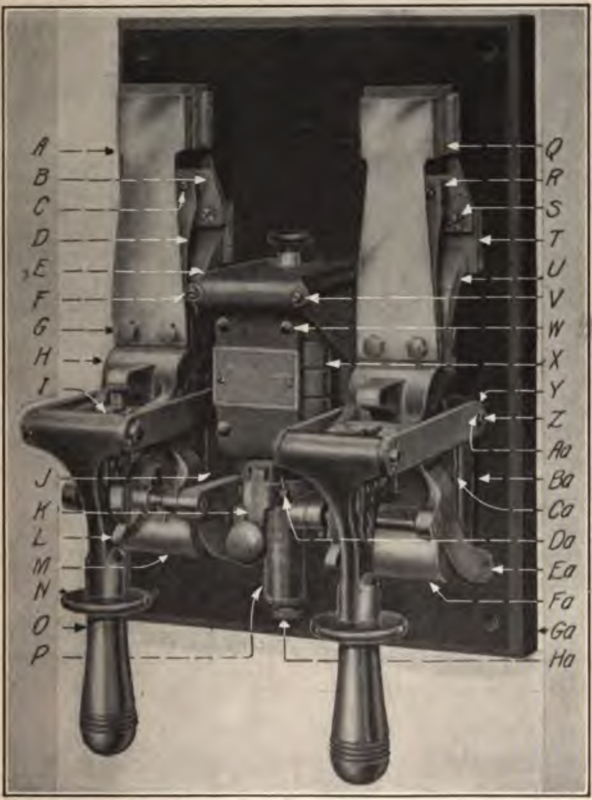


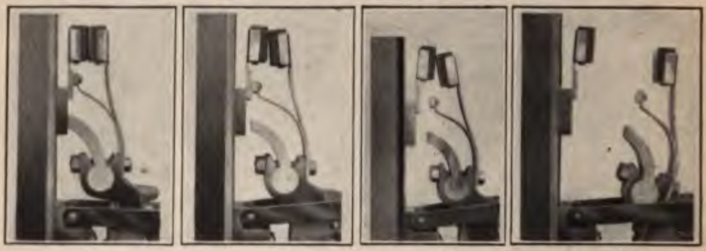

Fig. 255.—Double-Pole Circuit Breaker, showing Construction.

the normal current flowing through it; *B* shows the beginning of the separation of the contacts when the circuit breaker is opened by the action of an abnormal current—the main brush is open and the burning tip above it is just leaving contact; *C* shows the main brush and burning tip open and

the secondary carbon blocks at the top just leaving contact; *D* shows the circuit breaker fully open, with all the contacts widely separated.

**706. Are all circuit breakers made like those previously shown?**

The general operating principles and construction are practically the same; there are, however, single-pole circuit



A B C D

Fig. 256.—Action of Circuit Breaker in Opening.

breakers, three-pole circuit breakers, motor-operated circuit breakers for remote control of circuits carrying heavy currents, and circuit breakers for alternating- or direct-current operation on low voltage, over voltage, shunt trip or any combination of the above; also direct-current circuit breakers for operation on underload or reverse current. The circuit breakers shown in Figs. 253-255 are overload circuit breakers for direct-current circuits or low-voltage alternating-current circuits.

**707. What is a lightning arrester?**

A device for diverting a lightning discharge from the line wires to the ground without entering the station and interrupting the service.

**708. Illustrate and describe a form of lightning arrester for use on alternating-current circuits.**

The lightning arrester shown in Fig. 257 is one of this kind. Seven independent cylinders, *a, b, c, d, e, f, g,* of non-arcing

metal are mounted side by side upon a marble base. The cylinders are separated from each other by air spaces, but their surfaces are nurled to facilitate electrical discharges

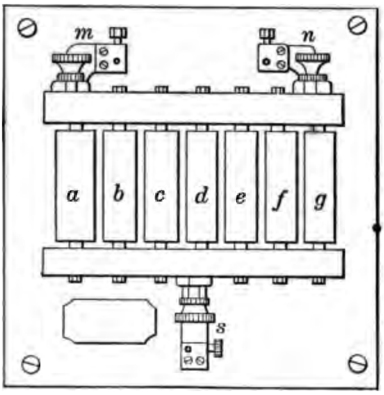



Fig. 257.—Multiple-Gap Lightning Arrester for Alternating-Current Circuits.

between them. The leads from the line wires are connected to the end cylinders by the binding posts *m* and *n;* the middle cylinder is connected to ground by the binding post *s*. A lightning discharge on the line will always seek and traverse the shortest and least inductive path, even though it be of

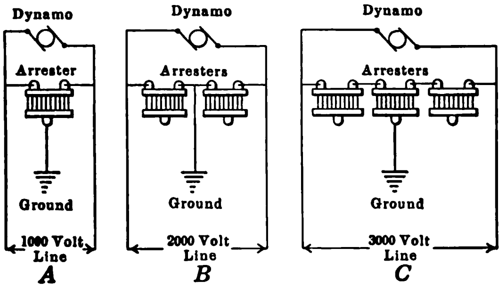



Fig. 258.—Connections of Multiple-Gap Lightning Arresters for Different Voltages.

a somewhat high resistance, and will therefore jump across the gaps between the cylinders from the line terminals to the ground in preference to traversing the high inductive

windings of generators or motors connected to the line. The non-arcing metal will not sustain an arc nor become fused by it.

**709. Is this lightning arrester always connected the same way regardless of the working potential of the line?**

No; when used on 1000-volt circuits, the arrester is connected as in Fig. 258 at *A;* on 2000-volt circuits two arresters are wired in series across the line as at *B,* the ground connection being made to the wire joining the two arresters; on 3000-volt circuits, three arresters are used, as at *C.*

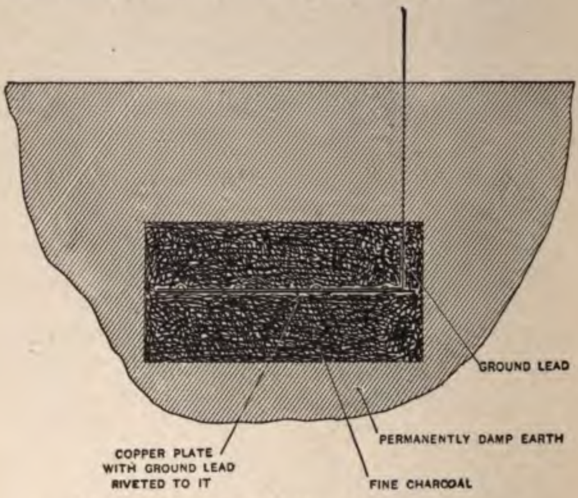



Fig. 259.—Standard Ground Connection.

**710. How may a good contact with the earth be obtained?**

Dig a hole four feet square, directly beneath the arrester. Dig down until permanently moist rich ground has been reached. Where permanent dampness cannot be reached, it is advisable to have water occasionally supplied to the ground through a pipe from some convenient source nearby. Cover the bottom of the hole with about two feet of crushed coke or charcoal (pea size). Over this lay 10 square feet of No.

16 tinned-copper plate, and solder the ground wire entirely across the surface of this plate, riveting it thereto at the end. Ground plates used in grounding station circuits should have considerably more area,—25 square feet or more, depending upon conditions, but 10 square feet is about right for lightning arrester grounds. The ground wire should preferably be of No. 0 copper. Cover the plate with about two feet of crushed coke or charcoal, and fill in the hole with the ground previously dug out, using water to aid it in settling. A ground connection of this kind is pictured in Fig. 259.

**711. What other forms of lightning arresters are adapted for use on alternating-current circuits?**

Lightning arresters, in which non-inductive resistances are shunted across portions of a group of metal cylinders, are


Fig. 260.—Multiple-Gap Lightning Arrester with Non-Inductive Shunts.

in common use. A 1100-volt single-pole arrester of the above type is shown in Fig. 260. It consists of a number of small, nurled cylinders *m*, etc., portions of which are shunted by two resistances *r* and *s*. The resistance rod *s* is of very low ohmic resistance and shunts a small number of spark gaps,

but the rod *r* is of high resistance and shunts a larger number of spark gaps. The terminal *a* is connected to the line, and the terminal *b* to ground. The arrangement of shunts gives practically three arresters in one unit as follows:

A lightning discharge of medium frequency will pass to ground through the low-resistance path, while low-frequency discharges and those due to steady static stresses will pass through the high resistance. Discharges of extremely high frequencies will find a comparatively difficult path through the resistances, and a relatively easy path across all the spark gaps. The various paths are designed to give the arrester

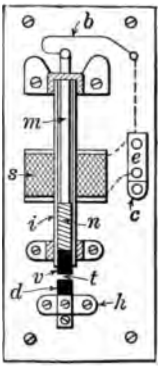



Fig. 261.—Lightning Arrester with Electro-Mechanical Arc-Breaker for Alternating-Current Circuits.

a uniform voltage breakdown regardless of the frequency or quantity of the discharge.

Single-pole units such as shown in Fig. 260 are assembled in groups to form double-pole and triple-pole arresters.

**712. Are there other types of alternating-current lightning arresters?**

The lightning arrester shown in Fig. 261 is another common form. In this the lightning discharge enters the arrester at the binding post *c*, thence passes through the non-inductive resistance *e*, which is shunted across the coil *s* by wires imbedded in the base of the arrester and indicated by dotted lines in the illustration, to the flexible cord *b*, to

the guide rod *m* and soft-iron armature *n*, which is normally in contact with and rests upon the carbon *v*. The discharge then jumps across the spark gap *t* to the lower carbon *d*, which is mounted in the bracket *h*, and passes to ground through a conductor fastened to *h*. The non-inductive resistance *e* has such a high ohmic resistance that sufficient current from the discharge is shunted through the coil *s* to cause it to quickly draw up the iron armature *n* and thus form an opening between the lower end of *n* and the upper carbon *v*. The arc which results at this point is inside the tube *i*, which is practically air-tight, so that the oxygen is instantly consumed and the arc extinguished. As soon as the current ceases, the coil *s* loses its power of attraction, whereupon the armature *n* drops of its own weight to its normal position on *v*, and the arrester is ready for another discharge.

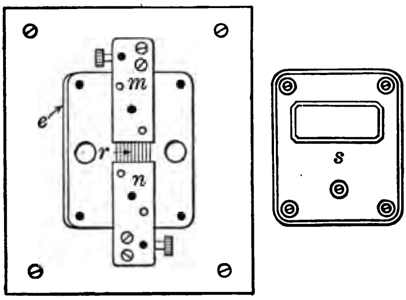



Fig. 262.—Non-Arcing Lightning Arrester for Direct-Current Circuits.

**713. Describe a lightning arrester for direct-current circuits?**

Fig. 262 shows a lightning arrester suitable for direct-current circuits up to 700 volts. Two metal electrodes *m* and *n* are mounted upon a lignum-vitæ block *e*, flush with its surface. The arrester is of the single-pole type, one of the electrodes being connected to the line and the other to ground. Charred or carbonized grooves *r* provide paths for the discharge. Upon the block *e* and covering the grooves and electrodes is placed a second lignum-vitæ block *s*. Lightning dis-

charges will readily pass between *m* and *n* over the charred wood in the grooves, but as this path has a resistance of over 50,000 ohms, there is no appreciable leakage of current.

**714. What other form of lightning arrester is suitable for direct-current circuits?**

Fig. 263 shows another type of lightning arrester designed for direct-current circuits. This arrester has two adjustable spark gap terminals *a* and *c*, composed of diverging fingers so that the arc lengthens as it is blown out. There are also a non-inductive carborundum resistance rod *e* of about 100 ohms in series with the spark gap, and a magnetic blow-out coil *m* in parallel with the resistance rod *e*, all completely

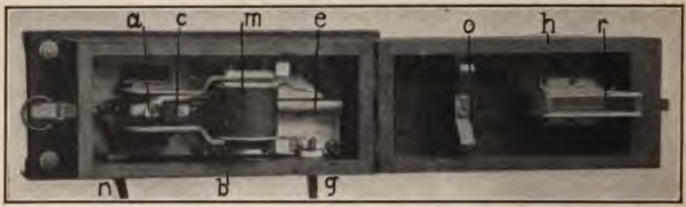



Fig. 263.—Magnetic Blow-Out Lightning Arrester for Direct-Current Circuits.

enclosed in a porcelain box *b* with hinged cover *h*. The line connection *n* is made to one side of the spark gap, the other side of which is connected through the non-inductive resistance rod *e* to ground by the conductor *g*.

Any attempt of the direct current in the line wires to follow a lightning discharge to ground is immediately interrupted at the spark gap by the action of the magnetic blow-out, the field of which is produced by the passage of the direct current through the shunted blow-out coil *m*, which latter, however, does not interfere in any way with the lightning discharge. In the cover is a porcelain blow-out chute *r*, which surrounds the spark gap and, with the porcelain partition *o*, prevents sparks from reaching other parts of the arrester.

**715. For what purpose are choke coils used?**

The purpose of a choke coil is illustrated in Fig. 264, where *b* and *c* represent the line wires of the dynamo *a*. Connected in series with *b* and *c* are the choke coils *h* and *m*, and close

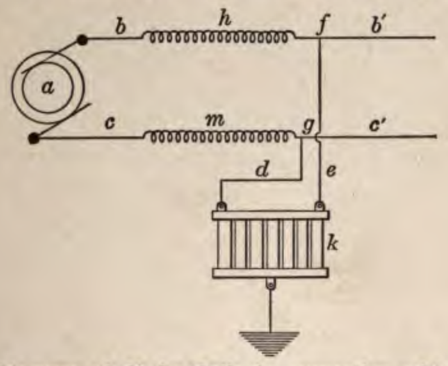



Fig. 264.—Diagram of Choke Coils in connection with Multiple-Gap Lightning Arrester.

to the outer ends of these coils are connected the wires *d* and *e*, which run to the lightning arrester *k*. A lightning discharge finds much difficulty in traversing a choke coil, because of its inductive winding, and coming in on the line wires *b′* and *c′*,

Fig. 265.—Choke Coil for High Voltage.

will "pile up," as it were, in front of the coils *h* and *m*. Before the charge becomes sufficient at *f* and *g* to pass through the coils *h* and *m*, it will find its way through the wires *d* and *e*, and through the arrester *k*, to ground.

Choke coils may also be used to advantage between a dynamo and a circuit breaker, where they will overcome, to

Fig. 266.—Low-Voltage Choke Coil.

some extent, the high-voltage reactive kick through the machine when the circuit is opened.

**716. How are choke coils made?**

For high-voltage circuits they are usually made of alumi-

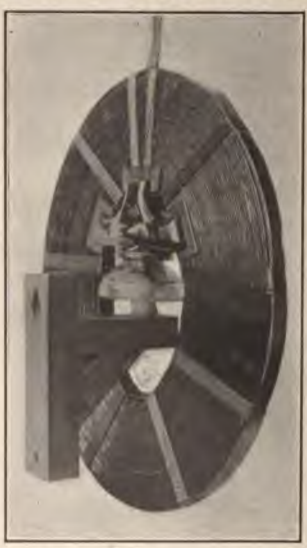


Fig. 267.—Choke Coil for Alternating Current of Low Frequency.

num rod wound in the form of a helix, as in Fig. 265, the convolutions being separated by air-spaces. For low voltages,

insulated wire is used, and the convolutions lie close together, as in Fig. 266. For low frequencies, requiring a large number of turns, the convolutions are usually put in concentric form, as in Fig. 267, for the sake of compactness. These coils are heavily insulated and have the line wire at the top, as shown. A bracket, as seen in the illustration, is generally used for mounting the coil on the wall, the coil being supported by clamps in the central opening.

## RHEOSTATS

**717. What is a rheostat?**

A device for introducing a variable amount of "dead" resistance in a circuit.

**718. How is a rheostat made?**

It usually consists of several coils of wire connected to a series of contacts, whereby more or less of the wire may be

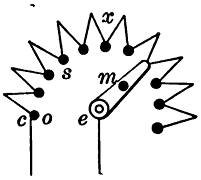



Fig. 268.—Diagram of Rheostat.

introduced as resistance in the circuit through a movable arm which engages with the contacts.

This is illustrated diagrammatically in Fig. 268, where one terminal of the circuit is shown at *e*, the resistance at *x*, and the other terminal of the circuit is shown at *c*, the amount of resistance introduced being controlled by the metal contact arm *m*. With the arm *m* at *o*, none of the resistance *x* is in circuit, but as *m* is moved toward the right over the studs *s*, it introduces in circuit at any one time the resistance of *x* between the stud upon which the arm rests and *o*.

**719. In what form are rheostats made?**

Rheostats are made as shown in Fig. 269 for mounting on the face of a switchboard or on a wall, post or table, and as

shown in Fig. 270 for mounting behind the switchboard. As a matter of fact, the rheostats are the same in both cases, but the contact arm *m* in the latter is connected by a rod *d* with the hand-wheel *w* which extends through to the front of the board, the iron arm *r* holding the rheostat behind the switchboard clear of the bus-bars and cables.

Referring to Fig. 269, the contact studs *x* are made of brass and arranged in the form of a circle on the slate top *s*,


Fig. 269.—Rheostat for General Service.

as shown. To these are connected the resistance units, mounted in the ventilated base *b*, which are all connected together in series and the end terminals joined to the binding posts *o* and *e*. Beneath the top there is a wire connection between *o* and *m*. Consequently, when the rheostat is connected in circuit at the binding posts *o* and *e*, with the contact arm *m* up against the left side of the stop *v*, no resistance is introduced, because the current entering at *o* passes direct to *m* and thence to the first of the contact studs and out at *e*. If, however, *m* be moved in a counter-clockwise direction, making contact with the successive studs, the resistances connected to them will be included in circuit, and when the arm is around on the stud at the right of the stop *v*, the

whole resistance of the rheostat will be introduced in circuit between *o* and *e*.

**720. How are the resistances used in rheostats, constructed and mounted?**

They should be of an alloy having a high resistance, a high fusing point and not appreciably affected by change in temperature. They should be of such size that they will not heat too much under the action of the current, and not vary in value while in service. When carrying their maximum current, their temperature should not rise above 195 degrees Fahrenheit.

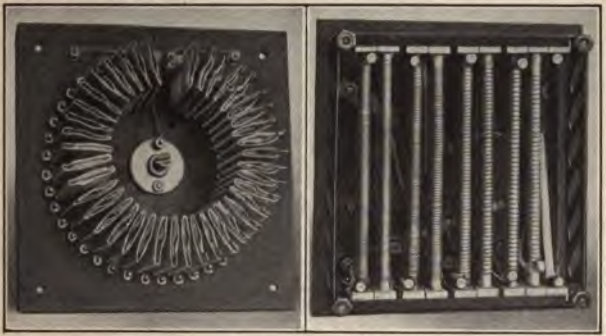


Fig. 269-A.—Two Methods of assembling Resistance in Rheostat, Fig. 269.

Attention is called to Fig. 269-A, which shows the construction and arrangement of the resistance in the rheostat, Fig. 269, according to two methods, both of which are in common use. In both cases the resistance is non-corrosive wire wound over fire-proof insulation on metal bars, the shape of the bars and the method of winding being such that no two adjacent turns of the uninsulated wire can come in contact with each other. At the left of Fig. 269-A the resistance wire is wound on short broad bobbins, which are mounted on the back of the face plate and perpendicular to it, by attaching them directly to the contact studs. In the right illustration the resistance wire is wound on long narrow por-

celain bars, which are mounted between opposite sides of the enclosing box, the ends of the bars resting in cored porcelain blocks, thus doubly insulating the wire from ground.

**721. Are the rheostats in Figs. 269 and 270 used in connection with generators and motors?**

They are used in the field circuits of generators to control the voltage, and in the field circuits of motors to control the

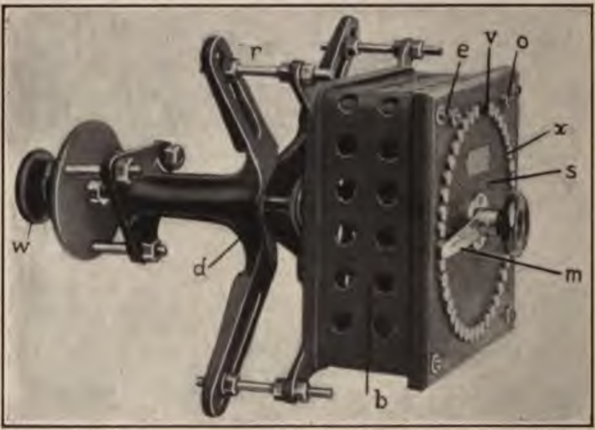



Fig. 270.—Rheostat arranged for Switchboard Mounting.

speed. In the starting of motors a specially equipped rheostat is used in the armature circuit.

**722. What special equipment is used in motor-starting rheostats?**

Motor-starting rheostats generally comprise a rheostat equipped with an automatic no-voltage release and sometimes an overload device.

**723. How are these rheostats used in starting up a motor?**

A motor-starting rheostat is used to prevent an abnormal current from passing through the motor when it is first connected to the line and to keep the current within safe limits during the acceleration period, after the armature begins to

revolve. As the accelerating period is usually not over 15 seconds in duration, the controlling function of a motor-starting rheostat is temporary only, that is, it is serviceable only while the motor is speeding up. The resistance conductor in the rheostat, therefore, is not designed to carry the full current longer than 15 seconds, or thereabouts.

**724. How do motor-starting rheostats protect a motor?**

If equipped with a magnetic no-voltage release they open the motor circuit automatically upon the failure of the current supply. It often happens that the supply of current is cut off and then suddenly turned on again. If the armature of the motor is in circuit and not protected at this time, the


Fig. 271.—Motor-Starting Rheostat with Automatic No-Voltage Release.

sudden rush of current through it might produce disastrous results in the way of damage to the armature.

**725. Show a motor-starting rheostat equipped with an automatic no-voltage release.**

Fig. 271 shows a motor-starting rheostat thus equipped. The automatic release is arranged so that when the supply of current is interrupted, the little magnet *a*, which is connected in series with the line through the resistance of the rheostat and holds the lever *s* in the " On " position, becomes demagnetized and allows the lever to fly back, under the influence of a spring, to its " Off " position, as shown in the illustration.

When the supply current is again turned on the main line, it cannot flow through the armature of the motor until the attendant moves the lever *s* over the series of contacts *m*, starting the motor gradually as before.

The retaining magnet *a* can be connected in series with the shunt field winding of the motor, and the armature will therefore be cut out of circuit if by any accident the field circuit should become broken. The resistance of this magnet coil is so small that it does not weaken the magnetizing effect of the field winding appreciably.

**726. What is the purpose of the overload attachment mentioned in Answer 722?**

To protect the motor from heavy overloads or short-circuits, and also to afford a convenient means of ascertaining the


Fig. 272.—Motor-Starting Rheostat with Overload and No-Voltage Release.

strength of the current in the armature circuit. The overload release is intended to act as a safety device only for overloads not greater than 50 per cent. above the rated capacity of the motor with which it is used. For overloads greater than this, fuses should be depended upon. This arrangement, however, permits using larger fuses, and thus

saves the annoyance and expense of frequently renewing them.

**727. Illustrate and describe a motor-starting rheostat equipped with an overload release.**

A motor-starter of this class is shown in Fig. 272. Aside from the overload attachment, the starter is similar to the one previously described. The overload release consists of a small magnet *m*, through the winding of which passes the full current of the motor. When this current becomes excessive, the magnet attracts its iron armature and opens the circuit of the retaining magnet *a* which holds the lever *s* at the "On" position. This circuit is opened by means of the insulating wedge *e* on the end of the armature lever flying up when the armature is attracted and separating the two metal contacts at *c*, thereby opening the circuit of the retaining magnet *a*. The retaining magnet *a*, losing its power, releases the rheostat lever *s*, which flies back, actuated by a spring in its hub, and by opening the circuit shuts down the motor.

**728. How is the resistance in a motor-starting rheostat constructed?**

In motor-starting rheostats of moderate capacity the conductor is in the form of high resistance, non-corrosive wire, wound around asbestos tubes, and the whole covered and baked. In the larger sizes, cast grids are used for the resistance.

**729. In case it is desired to vary the speed of a motor by changing the strength of the field, how is this arranged when a motor-starting rheostat such as the one just described is used?**

An adjustable resistance for varying the current in the field winding of the motor is connected in series with the no-voltage magnet, and both are connected in the shunt-field circuit. Motor-starting rheostats are made, however, in which the adjustable field resistance for speed variation is contained in them.

**730. Show and describe one of these combined motor-starting and regulating rheostats.**

Referring to Fig. 273, the apparatus consists of a motor-starter similar to those previously shown, and a series of buttons *d* connected to points in the field-regulating resistance, together with a field switch arm *o*, mounted on the same


Fig. 273.—Combined Motor-Starting and Regulating Rheostat.

hub post *r* as the starting arm *m* and cooperating therewith. The field switch arm *o* is so interlocking with the starting arm *m* that the former cannot be moved from the full field position until the latter is in the full " On " position. When the starting arm *m* is released by the no-voltage coil *a* and returns to the " Off " position, it carries the field switch arm *o* back to the full field position. A circuit breaker is included in this motor-starting and regulating rheostat set, as shown

at *k*, and the whole is wired up and connected in circuit as shown in Fig. 274.

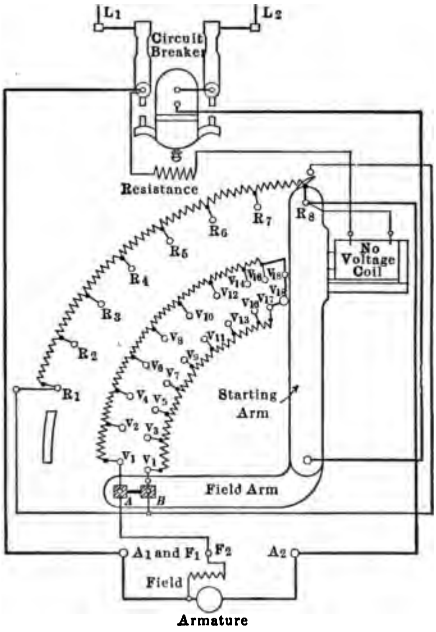



Fig. 274.—Diagram of Wiring and Connections of Rheostat in Fig. 273.

**731. How are motor-starting rheostats mounted on a switchboard?**

They are usually mounted at the lower part of the panel so that the handle of the contact arm is about 40 inches above the floor.

# SWITCHBOARD WIRING AND OPERATION

**732. How should the wiring on a switchboard be planned?**

The plan of wiring for a switchboard should be laid out so that the arrangement of instruments and other apparatus on the front of the board will be logical and symmetrical. No less attention should be paid to symmetry behind the board, for thereby the arrangement of wires and bus-bars is simplified, making it easier to discover and remedy defects than would otherwise be the case. Each conductor should run straight with one edge of the board; that is, it should be either vertical or horizontal. There should be as few bends as possible in large wires, and sharp turns at corners should be avoided in order not to strain or crack the conductors and their insulation.

**733. What distances should be allowed between the wires on a switchboard?**

That depends upon the difference of potential, or "voltage," between neighboring wires. Whatever this voltage be, the distance should be maintained uniformly throughout, and not diminished where the wires cross each other. A good plan consists in having all vertical wires in one vertical plane and all horizontal wires in another plane. For example, all horizontal wires may be located 6 inches from the board and all vertical wires 12 inches distant from it; then there will be a clearance of 6 inches between all vertical wires and all horizontal wires. This clearance may be reduced to 3 or 4 inches for low-voltage systems, but would make changing and repairing less convenient.

**734. Should switchboard wires be insulated?**

Yes, especially those on high-potential boards, in which

case wires insulated especially for high voltages should be used. When a wire is brought unusually close to the switchboard surface, or to another wire, it should be provided with additional insulation in the shape of tubing. Soft rubber is used considerably for this purpose, but it is not satisfactory because it deteriorates rapidly and is readily destroyed by heat and unfavorable atmospheric conditions. Metallic-covered tubing is unsuitable, for no metals should be brought near the switchboard except the conductors and necessary appliances. Flexible tubing composed of mica, etc., is mechanically secure, fireproof and a good insulator. This, or something similar, will give better satisfaction than the rubber compounds.

**735. How should the wires approach and leave the switchboard?**

That depends entirely upon local conditions. For low-potential plants of large current output the arrangement should be such as to make all connections as short as possible, but for high-potential systems, and in nearly all small plants, this precaution may be neglected if there are conflicting conditions of importance to be considered. The wires should not run back and forth any more than is necessary, and when the leads from the generators come to the board from below and the out-going mains leave from above, the switches and other circuit members should be arranged so that the current will be conducted through the apparatus in regular order upwards. When all wires approach and leave at the top or bottom of the board, it is customary to have all the leads from the generators on one side, and all the outgoing mains on the other side of the board.

## SHUNT GENERATORS

**736. Illustrate and describe how a switchboard should be wired for a shunt generator to supply current to one work circuit only.**

Fig. 275 gives a switchboard-wiring diagram for this case,

and represents the simplest form of switchboard wiring that occurs in practice. The wires behind the board are shown by dotted lines; the heavy lines represent the large wires or feeders which conduct the current to the out-going circuit,

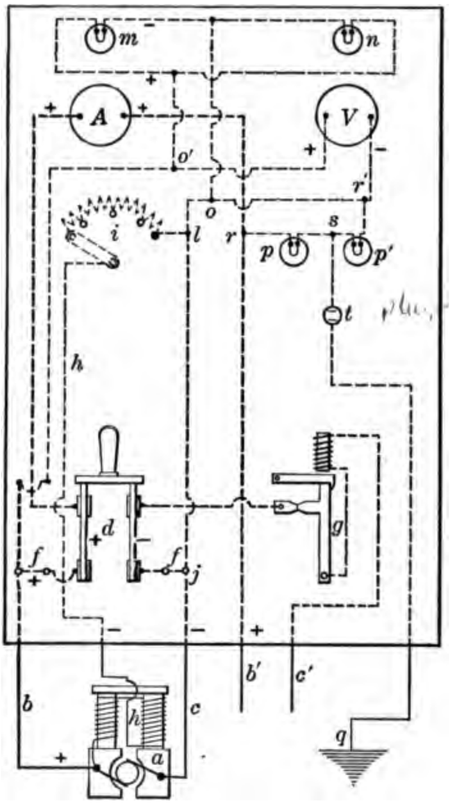



Fig. 275.—Switchboard Wiring for Shunt Generator feeding One Work Circuit.

and the fine lines represent the smaller wires making necessary connections.

Either terminal of the generator may be positive, but for the sake of simplifying the diagram the left-hand terminal is assumed to be positive and all wires connecting with that

side are designated +, accordingly. The negative lead *c* runs from the generator *a* to the fuse or safety cut-out *f*, thence to one blade of the double-pole switch *d*, from which it passes to the circuit breaker *g*, and then out on the line *c'*. From the positive terminal of the generator the lead *b* runs through another fuse to the other blade of the switch *d*, and thence to one terminal of the ammeter *A*; from the other terminal of the ammeter a wire passes out to the line *b'*.

So long as the switch *d* and the circuit breaker *g* are closed, the outside circuit completed and the dynamo *a* generating, there will be a flow of current in the wires mentioned. Both sides of the circuit may be opened by pulling out the switch *d*, and the negative side may be opened by the circuit breaker *g* being operated; if either of the fuses *f f* are blown, the circuit will be opened at that point. The fuses employed are usually of sufficient capacity that they will not be blown by a small overload, since they are supposed to act only when the circuit breaker fails to work properly. Sometimes the wires *b* and *c* are run first to the switch *d*, and then to the fuses *f f*, but the arrangement shown in the diagram is preferable because it protects the generator in case of an accidental short-circuit across the blades of the switch.

**737. For what purpose is the other wiring on the switchboard shown in Fig. 275 but not mentioned in Answer 736?**

For the control of the exciting circuit of the generator. Current must pass through its field winding and the terminals of this circuit are connected to the main terminals of the generator, but a rheostat is introduced in the circuit so that the field excitation, and therefore the voltage, of the dynamo may be regulated. In Fig. 275 one terminal of the field winding is connected directly to the positive terminal of the generator; the other terminal of the winding, instead of connecting directly with the other terminal of the machine, is connected by a wire *h* with the rheostat *i* on the switchboard.

It is not necessary to run a wire from the other terminal

of the rheostat *i* all the way back to the negative terminal of the generator, for the wire *c* extends from this terminal to the board, and connection may be made with it at the point *l*. This point may be anywhere on the negative wire *c* so long as its location will not cause the field circuit to be disconnected when the main circuit is opened by either fuse, switch or circuit breaker.

**738. How about the voltmeter connections?**

One terminal of the voltmeter *V* is connected to the negative terminal of the generator at *l*; the other voltmeter terminal is directly connected with the wire *b*, running to the positive terminal of the generator. It will be noticed that this positive voltmeter lead crosses over the positive main *b'* near the voltmeter, and it may puzzle the reader to know why the connection is not made here. The reason is that whenever the main switch *d* is open, the voltmeter would be disconnected from the generator. This would not be satisfactory, since it is desirable to know the voltage of the machine before the main switch is closed.

**739. What are the parts marked p and p' in Fig. 275?**

These are incandescent lamps which constitute a ground detector, as described in Answer 609, the ground circuit of which is closed or opened at the plug *t*. Connection is made with the positive side of the circuit at *r*, and with the negative side at *r'*. The two lamps *p* and *p'* are connected in series, and the ground wire is connected between them at *s*. The wire passing to the ground at *q* runs through the plug *t*, so that the detector may be cut off, or simply connected in at intervals, as desired.

**740. For what purpose are the lamps m and n, Fig. 275?**

To illuminate the dials of the ammeter and voltmeter. They are connected in parallel across the wires leading to the voltmeter. One side of the lamp circuit connects at *o*, and the other side connects at *o'*.

**741. How should a switchboard be wired for a shunt**

**generator which is to supply current to more than one work circuit?**

Fig. 276 gives a switchboard-wiring diagram for this case. Bus-bars are now needed, or rather they are extremely convenient, if not absolutely necessary. The increase in the

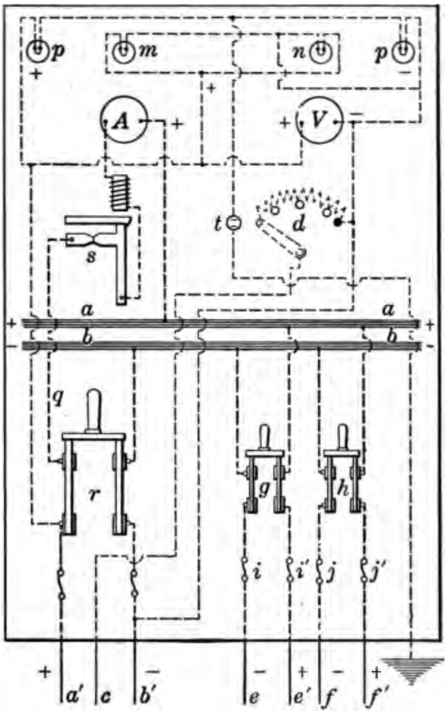



Fig. 276.—Switchboard Wiring for Shunt Generator feeding Two Work Circuits.

number of work circuits also changes the plan of the switchboard wiring from that in Fig. 275. The positive lead from the generator is now represented by the line *a*′; the negative lead by *b*′, and *c* is the field rheostat connection. Instead of running the leads from the switch *r* and the instruments directly to the out-going or work circuits they are carried to the bus-

bars. The difference of potential between the positive bus-bar *a* and the negative bus-bar *b* is practically the same as the voltage of the generator, and by making the proper connections they will supply as many work circuits as desired. Two work circuits are shown at *e e'* and *f f'*. Two double-pole switches *g* and *h* are connected in these circuits, and by means of them either or both of the circuits may be opened or closed. The fuses *i i'* and *j j'* are connected in to protect the circuits in case they become short-circuited.

In Fig. 276 the locations of some of the apparatus have been changed from those in Fig. 275 for the sake of symmetry and convenience. The circuit breaker *s*, for instance, has been placed directly over the main switch *r*, to avoid the necessity of having to cross the board with the wire *q*. The ground detector lamps *p* and *p* are located near the upper corners of the board, where they are out of the way. The plug *t* in the ground wire of the detector lamps is near the center of the board and in a convenient place.

In the wiring diagrams thus far presented, the leads from the generator connect with the main switch before running to the circuit breaker. This method has been followed in order to make the first diagrams as simple as possible; it is somewhat safer, however, to run the leads from the generator directly to the circuit breaker, and this method will be followed in subsequent diagrams.

**742. How is a switchboard wired for the three-wire system described in Answer 297?**

Fig. 277 shows the switchboard wiring for a three-wire system. In this illustration, *a* and *a'* represent two ordinary shunt-wound machines. Since there are three main wires, there are three bus-bars, *v*, *w* and *x*, of which *w* is the neutral bus-bar and connects the negative side of the dynamo *a* to the positive side of the dynamo *a'*. The lead from the positive side of the dynamo *a* runs through the circuit breaker *b*, the ammeter *A* and the switch *d* to the bus-bar *v*. In the same manner the negative terminal of the dynamo *a'* is connected

with the circuit breaker $b'$, the ammeter $A'$, the switch $d'$ and the bus-bar $x'$. This makes the bar $v$ positive and the bar $x$ negative; since the dynamos are rated at 110 volts each, there is a difference of potential between the bus-bars $v$ and $x$ of 220 volts, while the pressure between the neutral bus-bar $w$ and either one of the main bus-bars is 110 volts.

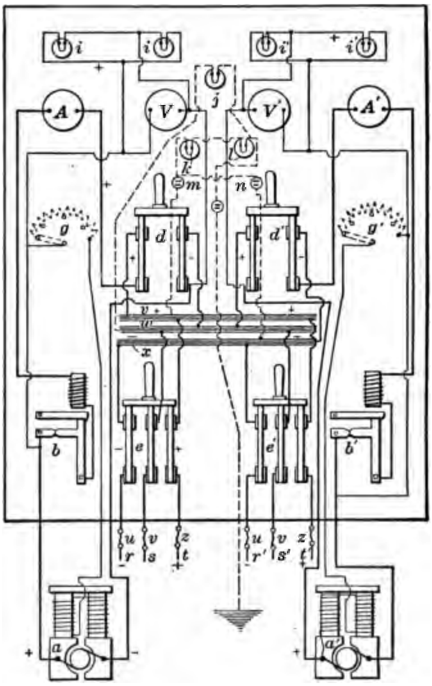


Fig. 277.—Switchboard Wiring for Two Shunt Generators feeding Two Work Circuits on Three-Wire System.

As many circuits as desirable may be connected to the bus-bars, two being shown in the illustration connected through the switches $e$ and $e'$. Since each circuit from the bus-bars consists of three wires, three-pole switches are necessary. The fuses are connected to the wires of each circuit as shown at $u$, $v$ and $z$, in each case. Each machine is provided with its

own instruments and appliances, which are connected the same as if there were only one machine wired to the switchboard.

**743. Explain the method used in Fig. 277 of wiring the ground detectors in circuit.**

The ground detector connections are shown dotted so that they will not be confused with the other lines. The lamps are shown at *j*, *k* and *l*, and *m* and *n* represent the plugs used to connect the apparatus with either one of the mains. The

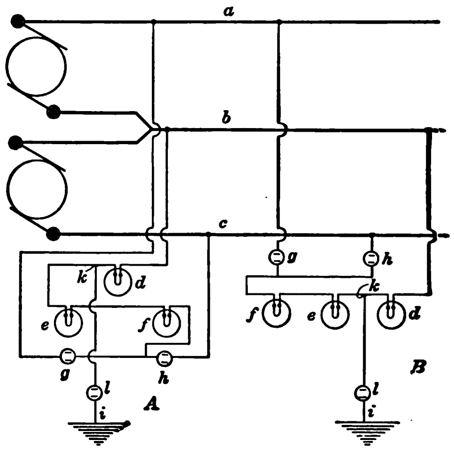



Fig. 278.—Ground Detector Connections.

principle of the detector connections is more clearly illustrated in Fig. 278. Here *b* is the neutral wire, and *a* and *c* are the outside wires of the circuit. At *A* the lamps are shown in the same relative positions as in Fig. 277; at *B* they are connected in the same manner as at *A*, but are differently arranged. The letters indicating the circuits and devices are the same in both parts of the diagram and the explanation which follows applies to both.

The three lamps are shown in Fig. 278, at *d*, *e* and *f*, connected in series with each other. One of the terminals is connected to the neutral wire, and the other terminal may

be connected with either of the main line-wires, *a* or *c*, by means of plugs *g* and *h*. At *k* the ground wire *i* is connected through the plug *l*. So long as all plugs are out, the lamps will be dark; if there be no ground, the lamps will remain dark when the plug *l* is inserted. If, however, there be a ground on either one of the main wires *a* or *c*, the lamp *d* will burn brightly when the plug *l* is inserted, leaving the lamps *f* and *e* dark. Knowing that there is a ground on one of the two main wires, the plugs *g* and *h* are tried, one at a time. When the grounded side is plugged, the condition of the lamps will remain the same, but if the side clear of grounds be tested, all of the lamps will light to candle-power. When there is a ground on the neutral wire *b*, it will be impossible to light the lamp *d* while the ground plug *l* is in; and the lamps *f* and *e* will be only red, or not up to candle-power, while either of the outside or main wires is being tested.

744. **What general precautions should be observed before starting up a direct-current generator?**

Notice must be taken that everything is in proper running order. First of all, the machine must be clean, and all bolts and screws must be properly tightened. The connections must be in good condition, that is, every wire must be in its place, and there must be no unintentional grounds or short-circuits. The oil cups must be filled to the proper height as indicated by the gage, and the oil rings must be free to move. Care must be taken to have the brushes correctly adjusted and set.

745. **In starting up a new machine, what general rules should be followed?**

Before applying the source of power, the rotating part of the generator should be turned around a few times by hand to see that the shaft moves freely. Then it should be started up under power very slowly, and watched closely so that it may be stopped immediately if anything goes wrong. When it is nearly up to normal speed the switch in the field circuit may be closed, but all the field rheostat resistance should be in

circuit. If a comparatively low voltage is then generated, the machine may be brought to its normal speed, after which the rheostat resistance should be cut out gradually until the full working voltage, or a little less, is obtained. In this condition the machine should be allowed to run for several hours without load.

The circuit to which it is to be connected should have a comparatively small load at first. The fuses then being in position, and of the proper rating, the circuit breaker may be closed and then the main switch closed. The ammeter should at once be observed; if everything is all right, its indication of amperes will be relatively low. The voltage may then be brought up very gradually. For a few hours both the current and the voltage should be kept somewhat below the normal rating of the generator.

After it is known, beyond doubt, that the bearings, windings and other parts of the machine are working properly, the load may be gradually increased, but it is usually advisable not to make it very heavy for several days. If the machine has any serious faults, they are liable to make themselves evident during this time, and it may be possible to apply a remedy, if necessary, before serious injury is done. While changes in load are being made, every part of the machine should be carefully watched, especially in regard to the temperatures of the different parts.

**746. How should a direct-current generator be shut down?**

If operated alone, it should be shut down by cutting off the motive power; the current will then gradually decrease to zero, and when the machine has stopped, the main switch and circuit breaker may be opened without sparking or other difficulty. Except in an emergency, a generator should never be disconnected from the circuit it is feeding until the current in that circuit has been reduced to a minimum. The discharge of magnetism, the mechanical shock and the flashing at the contact points where the circuit is opened, unless the

opening takes place in a circuit breaker which is intended for this usage, are likely to damage the affected parts.

**747. What precautions are necessary in operating shunt generators in parallel?**

Before switching a generator in parallel with one that is running and carrying a load, it is necessary to make sure that the positive terminals of both machines will be connected to the same bus-bar when the switch is closed, and likewise the negative terminals to the other or negative bus-bar. The voltage of the machine which is to be " thrown in " circuit should be brought up until it is one or two per cent. higher than that of the loaded machine. The main switch of the " in-coming " generator may then be closed, and by watching the ammeters and regulating the field rheostats in accordance therewith each machine can be made to take its share of the load.

**748. How should a shunt generator which is operating in parallel with others be shut down?**

The resistance in its field rheostat must be cut in until the ammeter in the main circuit of the machine indicates that it is carrying only a very small current. Then the circuit breaker may be opened and the generator shut down. Particular care must be exercised not to open the shunt-field circuit of a generator that is running in parallel with another, as that would cause one of the machines to be short-circuited through the other, and without the operation of a quick-acting circuit breaker or fuse it would cause the burning out of both armatures.

**749. Illustrate and describe how a switchboard should be wired for shunt generators to be operated in parallel.**

Fig. 279 shows the plan of switchboard wiring for three generators connected to the wires at *a*, *c* and *e*. Only two bus-bars, *h* and *m*, are employed, one of which is connected to the positive terminals of the machines, while the other is connected to the negative terminals. To these bus-bars are also connected the out-going wires at *b*, *d* and *f*. The out-

going circuits may be increased to any number and can be worked up to the combined output of the generators.

The lamp and ground-detector connections have been omitted, since they are exactly the same as in the preceding dia-

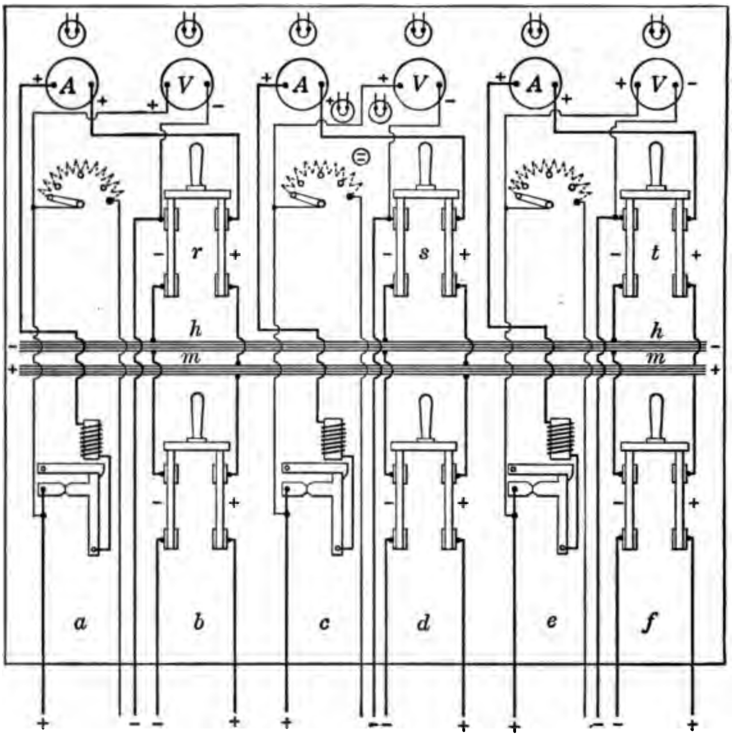



Fig. 279.—Switchboard Wiring of Shunt Generators operating in Parallel.

grams. The negative wires from the generators run to the upper terminals of the switches *r*, *s* and *t*, instead of to the lower terminals as in the previous diagrams. Either method is permissible, the one providing the most convenience in any particular case being preferable. Each generator circuit has its own ammeter, which is always necessary, and there is also a voltmeter for each machine. It is possible to operate with

only one voltmeter on the board, but it is advisable to have at least two, one connected to the bus-bars, and the other so wired that it may be connected with any one of the generators by means of a switch. The most satisfactory method, however, consists in having one voltmeter for each generator.

## SERIES GENERATORS

**750. Can two series generators be operated satisfactorily on the same circuit?**

They can if connected in series. Fig. 280 shows two series generators, *a* and *b*, thus connected across the bus-bars *h* and

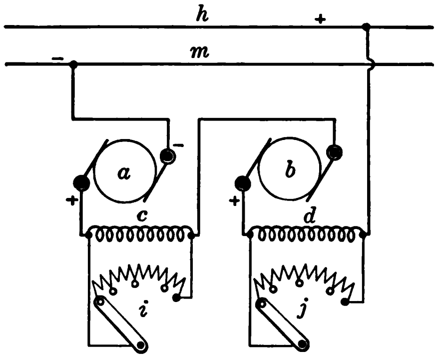



Fig. 280.—Diagram of Two Series Generators connected in Series.

*m*. The positive terminal of *a* is connected to the negative terminal of *b*, the positive terminal of *b* is connected to the bus-bar *h*, and the negative terminal of *a* is connected to the bus-bar *m*. The helix *c* represents the series field winding of *a*, and *d* the series field winding of *b*.

To make each machine do its share of work, that is, generate the same voltage, it is necessary to provide means for regulating the current in the field windings, *c* and *d*. To accomplish this, rheostats *i* and *j* are connected in shunt with the field windings, and by means of these the current in the windings is regulated. By moving the arm of the rheostat *i*, for example, so that some of the shunt resistance is cut out,

the current through the shunt will be increased, that in the field winding *c* will be decreased and the voltage of the generator *a* will, consequently, be diminished. The voltage of the generator *b* may be similarly regulated by the rheostat *j* in shunt with the field winding *d*.

**751. Can series generators be operated satisfactorily in parallel?**

They will not operate in parallel if connected up like shunt machines in parallel, for a drop in the voltage of one generator will cause that machine to drop a part of its load, and this, in turn, will diminish the strength of its field and

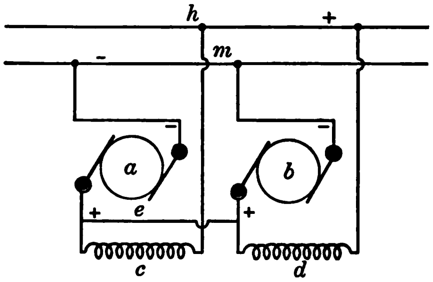



Fig. 281.—Diagram of Two Series Generators connected in Parallel.

cause the load to drop off still more. As its load drops, the voltage decreases and soon reaches a point where the other machine running in parallel with it will overpower this one and operate it as a motor; this condition would be injurious to both machines. The difficulty may be overcome by keeping the voltage always the same across the field windings of both generators. To insure this, the field windings of the machines are connected in parallel, as shown in Fig. 281. Here *c* and *d* are the field windings of the series generators *a* and *b*, respectively. One end of each of the field windings is connected directly to the bus-bar *h*, and the other ends are connected to a heavy wire *e*. This connection causes the difference of potential between the two ends of both field windings to be the same, so that the current is equally divided

between the two windings. Each machine will, therefore, have the same field strength and generate the same pressure, and if for any reason one machine becomes weakened, the stronger one will build up the weaker one. Since the wire *e* serves to equalize the pressure across the two field windings, this wire is called an "equalizer."

## COMPOUND GENERATORS

**752. Can compound generators be operated in series satisfactorily?**

They can. Fig. 282 shows two compound generators *a* and *b* connected in series across the mains *h* and *m*. The shunt

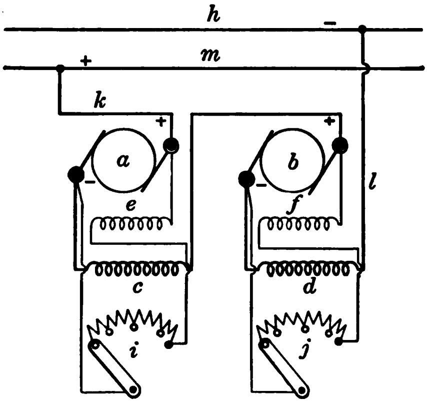



Fig. 282.—Diagram of Two Compound Generators connected in Series; Separate Field Control.

field windings *e* and *f* of the two machines are controlled by the rheostats *i* and *j*. When two compound generators are operated in series regularly, it is advisable to have them of the same size and type so that their voltages will always be equal. The two shunt windings *e* and *f* may then be connected in series with each other and with a controlling rheostat *g*, as illustrated in Fig. 283. This method insures equal field excitation and, consequently, proper division of the load.

**753. Can compound generators be operated in parallel satisfactorily?**

Yes. Parallel operation is one usual method of working

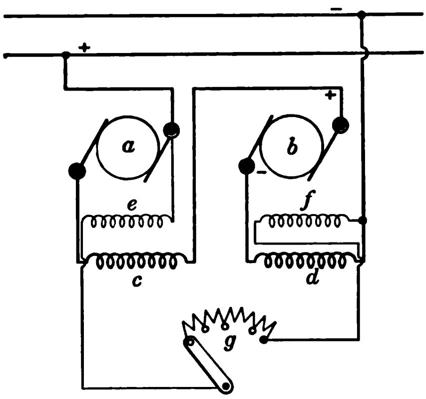



Fig. 283.—Diagram of Two Compound Generators connected in Series; Common Field Control.

two or more compound generators together. The connections are shown diagrammatically in Fig. 284. The equalizer, which

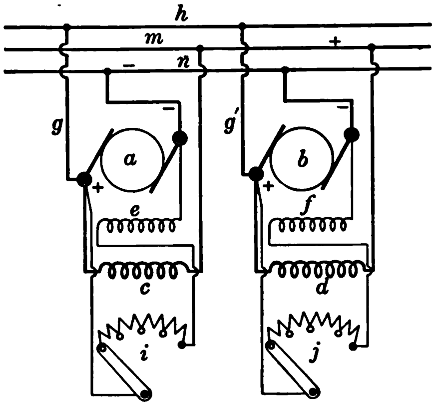



Fig. 284.—Diagram of Two Compound Generators connected in Parallel.

maintains an equilibrium between the electromotive forces of the two machines, is the principal feature to consider. It

consists of two heavy wires, $g$ and $g'$, running to an extra bus-bar $h$, which connects them and thereby completes the equalizing circuit. The equalizing circuit is carried to the switchboard and wired through a switch in order that it may be closed and opened at the same time the machines are connected with or disconnected from the main bus-bars.

Care must be taken to connect the equalizer to the junctions between the series windings and the brushes of the machines, —not to the outer terminals of the series windings. To insure good regulation, the equalizer must have ample current-carrying capacity; it should never be smaller than the main leads of the generators connected.

**754. What precautions are necessary in operating compound generators in parallel?**

Before switching them together the voltages must be nearly alike, the voltage of the unloaded machine being a trifle higher than that of the one already in use. If the equalizers run to the main switches on the board, no attention need be paid to them, as they will be connected at the same time the machines are thrown together. If, however, the equalizing wires are separate, care must be taken to close the equalizer switches at the same time the machines are thrown together.

The terminals of both machines to which the shunt resistances across the series windings are fastened must be connected to the same bus-bar. Then if the polarity of the generator is wrong, it must be corrected by exciting the field properly with current from another machine. Care must be taken not to open the equalizing circuit of two compound generators while they are running in multiple.

**755. Show a switchboard and its wiring for operating a compound-wound generator.**

In Fig. 285 the three-panel switchboard is equipped for a single compound-wound generator to supply six feeder or work circuits. The left panel contains the equipment for controlling the generator and the other two panels contain

the fused switches for the six feeder circuits. Fig. 286 gives the wiring diagram for the generator panel and one feeder panel, as viewed from the rear, the remaining feeder panels being a duplicate of the one shown.

It will be noted that the main switch *d* of the generator is wired to an equalizer bus-bar; this, of course, is not used in the present case, but is ready for connection in case another


Fig. 285.—Switchboard equipped for Single Compound Generator supplying Six Feeder Circuits.

generator and panel become necessary, so as to operate the machines together in parallel for carrying additional load. The generator circuit is protected by a single-pole circuit breaker *b*, and each of the feeder circuits by enclosed fuses *f*, etc. The handwheel *w* operates a rheostat mounted on the back of the board and connected in the shunt field circuit of the generator. The voltmeter and ammeter are shown side by side above the handwheel, and above these are the ground detector lamps *a* and *e*. The main connections between apparatus and to the bus-bars are made with copper strap. The

bus-bars are supported from the framework by means of brackets fitted with porcelain insulators.

**756. When two or more compound generators are used together for giving 110-volt service, how are they generally connected?**

To a three-wire system, as illustrated in Fig. 287. Four

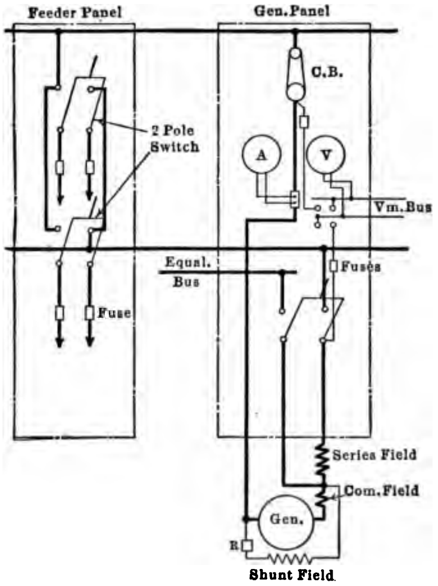



Fig. 286.—Wiring Diagram of Switchboard in Fig. 285.

compound generators are there shown, two being connected on each side of the neutral wire. As many machines as desirable may thus be connected, taking care that all of those on each side of the neutral are properly connected in parallel. In the diagram, *j* is the neutral bus-bar, *i* the negative and *l* the positive bus-bar. The generators *r* and *s* are connected on the negative side, and the generators *t* and *u* on the positive side of the system. In the connections for the generators *r* and *s*, the wires *a* and *d* run to the negative bus-bar *i*, and

the positive wires *b* and *e* run to the neutral bus-bar *j*, to which are also connected the negative wires of the generators *t* and *u*. The equalizer wires of generators *r* and *s* extend to a separate bus-bar *k*, and in order that they may be simultaneously connected with and disconnected from the mains they are led through the same switches, *g* and *h*. On this account the switches *g* and *h* are provided each with three blades, the

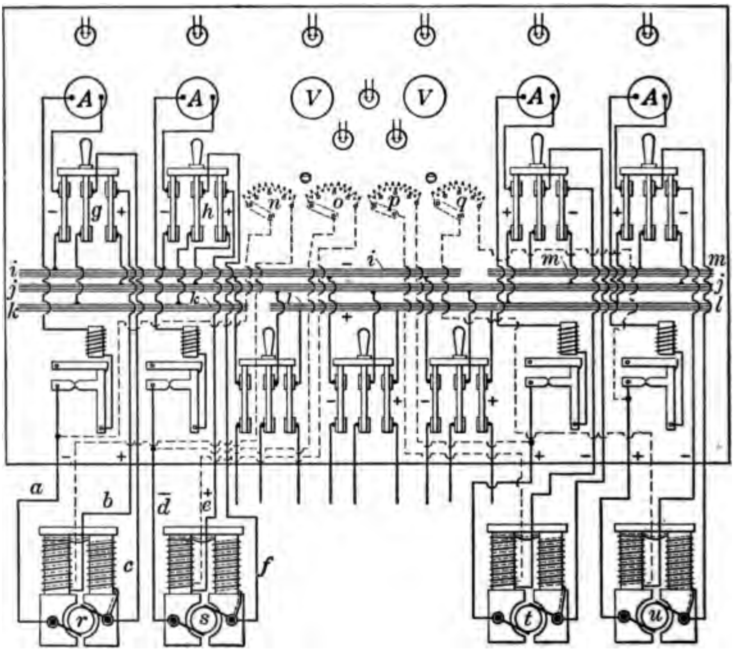



**Fig. 287.—Switchboard Connections for operating Four Compound Generators on Three-Wire System.**

middle one controlling the equalizer connection. The jaws receiving the middle blade are a fraction longer than the others, so that when the switch is thrown in, the equalizing circuit will be closed a trifle sooner than the main circuit. This is to avoid the danger of having one machine feed into the other one.

The equalizing wires of the generators *t* and *u* are con-

nected through the bus-bar *m* and the positive wires are connected to the bus-bar *l*. The current for the line passes out on the positive wire from the generators *t* and *u*, and after passing through the outside circuit returns through the bus-bar *i* to the negative terminals of the generators *r* and *s*. Any one of the machines may be provided with a double-throw switch by means of which it may be connected to either the positive or the negative side of the system. The reader should

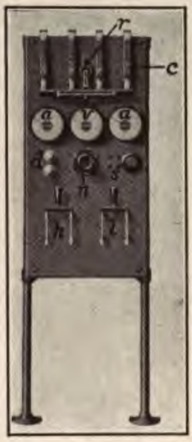


Fig. 288.—Switchboard Panel for Direct-Current Three-Wire Generator.

be careful not to confound the equalizing bus-bars with the others.

The field rheostats *n, o, p* and *q* are located behind the center of the switchboard, where there is the most space for them; their connections are indicated by the dotted lines. Only two voltmeters are provided, one being connected between the neutral and the positive bus-bars and the other between the neutral and the negative bus-bars.

**757. How is a switchboard arranged and connected for a direct-current three-wire generator to supply current to a three-wire system?**

A completely equipped switchboard panel for a direct-current three-wire generator is shown in Fig. 288. The diagram of connections in Fig. 289 shows how the generator is connected to the apparatus on the switchboard generator panel when viewed from the rear, and how this in turn is connected with the fused switches on one of the feeder panels.

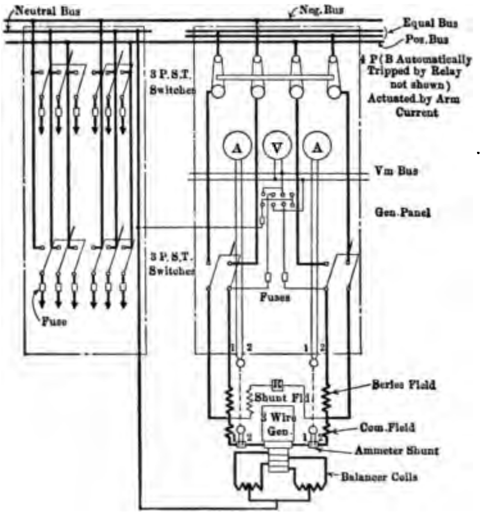



Fig. 289.—Connections of Switchboard in Fig. 288 to a Three-Wire Generator and One Feeder Panel.

At the top of the generator panel is a four-pole carbon circuit breaker *c* automatically tripped through a relay *r* when actuated by an abnormally high armature current. Below this is a voltmeter *v* and two ammeters *a* and *a*, the latter wired to ammeter shunts mounted on the generator frame in the two outside wires. Next below the meters on the left is the ground detector *d*, which consists of two 220-volt incandescent lamps connected to the circuit so as to form a continuously indicating detector. One lamp is connected between each positive or negative line and ground. In line with the lamps is the handwheel *n* of the generator field rheostat and the voltmeter switch *s*, and below these are the two

double-pole switches *h* and *l* in the armature leads to the bus-bars.

Switches are not provided for disconnecting the balance coils from the collector rings on the generator, as these circuits can be opened by lifting the collector brushes.

**758. How should a switchboard be arranged for allowing any of the generators in the plant to be excited from the bus-bars, in case some of them become demagnetized or will not build up readily?**

The switchboard equipment and wiring should follow a plan such as shown in Fig. 290. The bus-bars *h* and *m* are supplied with current by one or more of the generators *a*

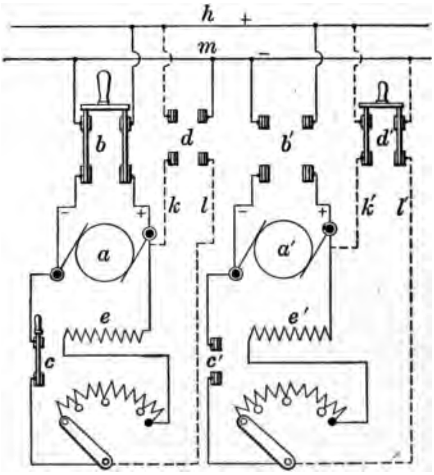



Fig. 290.—Diagram of Connections for Generators to be Temporarily Excited from the Bus-Bars.

in the plant. Suppose the generator *a′* should have difficulty in building up when started. By closing the switch *d′* in the auxiliary circuits *k′ l′* the full pressure on the bus-bars will be applied to the field winding *e′*, the current passing through the wires represented by dotted lines. When the voltage of the generator *a′* has come up to its normal value, and the

switch $b'$ has been closed, the switch $c'$ may be closed and $d'$ opened, as shown for the machine *a*.

Each generator in the plant may advantageously be connected in this manner. It will be noticed that the auxiliary circuits of the generators *a* and $a'$ include the field-circuit rheostat. If these were connected between the rheostat and the field winding, it would not be possible to regulate the voltage of the machine while the switch *d* or $d'$ was closed.

## ALTERNATORS

**759. Does the switchboard wiring for alternators follow any general plan, or does the wiring differ for each particular case?**

Each case generally has some feature peculiar to itself, but the principles in general are the same in all cases.

**760. Show the usual method of switchboard wiring for a single-phase alternator and its exciter.**

Fig. 291 shows one arrangement. Here *a* is the alternator and *b* the exciter generator; the field windings of these machines are indicated by *p* and *q*, respectively; the direct-current conductors are represented by dotted lines, and the solid lines represent wires that conduct alternating current. The field magnet of the alternator is excited by current from the generator *b*, carried by the wires *d* and $d'$, which terminate at the lower terminals of the double-pole switch *g;* the upper terminals of this switch are connected with the field winding *p* and the rheostat *e*. The rheostat *f* is connected in the field circuit of the exciter *b*, and is used to regulate the voltage of the exciting current.

**761. Why are some of the wires in Fig. 291 represented by heavy and some by light lines?**

The main wires from the alternator are represented by heavy lines and are identified by the letters *c* and $c'$; they are connected through the fuses *j* and *i*, to the lower terminals of the double-pole switch *k;* from the upper terminals of this

switch, wires run to the single-pole circuit breakers *r* and *s*. From here *c'* runs to the bus-bar *m*, and *c* is led to the bus-bar *h* after passing the ammeter *u*. Outgoing work circuits may be connected to the bus-bars *h* and *m;* if there are two

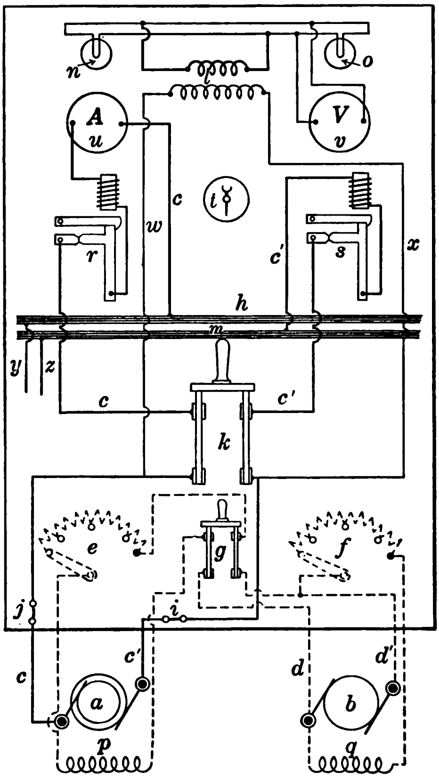



Fig. 291.—Switchboard Wiring for Single-Phase Alternator and its Exciter.

or more out-going circuits, each should be provided with a switch, which may be located on the switchboard at either side of the main switch *k*.

**762. What are the coils indicated at l, Fig. 291?**

The alternator *a* is usually of too high a voltage to have

lamps or other electric appliances connected directly to its mains; a small transformer *l* is therefore provided and located behind the board, for the pilot lamps *n* and *o*, and the voltmeter *v*. The primary terminals of the transformer are connected to the alternator leads *c* and *c'* by the wires *w* and *x*; these wires must be connected to the lower terminals of the switch *k* so that the transformer will not be disconnected when the switch is open. To the secondary winding of the transformer are connected the pilot lamps *n* and *o*, and the voltmeter *v*. At *t* is a ground detector, which may be of any type suitable for alternating currents and the voltage of the circuit to which it is connected. The connections of this detector are not shown because they depend upon the kind of ground detector adopted.

**763. Why are safety fuses and circuit breakers both used?**

Fuses are connected between the alternator and the main switch, in order that they may protect the machine regardless of the position of the main switch blades. Circuit breakers are seldom used when the voltage is above 3000, but for low voltages they may be used to good advantage beyond the main switch to protect promptly against external short-circuits. They should be of the single-pole type to prevent a short-circuit from the arc that occurs when the circuit breaker operates.

**764. Show the usual arrangement of apparatus on a low-voltage three-phase switchboard and the method of wiring employed.**

Fig. 292 shows a two-panel switchboard equipped for a single three-phase alternator of 110, 220 or 440 volts and 600 amperes, to supply current to two feeder circuits. The alternator or generator panel at the left is fitted with three ammeters, one for each phase, and a single voltmeter, which are connected in circuit as shown in Fig. 293. By means of a voltmeter plug, the voltmeter connections can be conveniently shifted at will across any of the phases.

Below the center of the generator panel is a small switch by means of which the exciter current is led to the field of the alternator, and also a large switch in the main leads of the alternator. The handle of the exciter rheostat, which latter is mounted on the rear of the panel, projects through the front of the board. The ground detector lamps form a continuously indicating detector, one lamp being connected between each wire and ground; a 110-volt lamp is used on a 110-volt

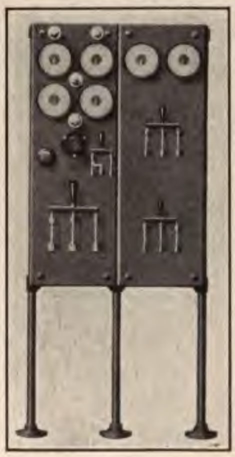


Fig. 292.—Three-Phase Switchboard for Low-Voltage Service: One Generator Panel and One Feeder Panel.

circuit, a 220-volt lamp on a 220-circuit and two 220-volt lamps in series on a 440-volt circuit.

It will be noted that the diagram of connections in Fig. 293 is given as the wiring appears when viewed from the rear of the board, and shows the wiring for but one feeder circuit. The second feeder circuit is, of course, wired in the same way, and provision is made for synchronizing by lamps in case it is desired to add another generator panel and alternator in parallel with the one shown.

**765. What is the usual form of equipment and wiring on a three-phase switchboard for high-voltage service?**

On boards of this type the main switching devices are

mounted apart from the panels and electrically operated from apparatus on the panels. On the board illustrated in Fig. 294, drum type control switches with signal lamps are mounted on the panels at *r, s, m* and *n* for this purpose. This switchboard comprises five panels, of which *A* is the exciter panel for two compound-wound exciters; *B* and *C*, generator

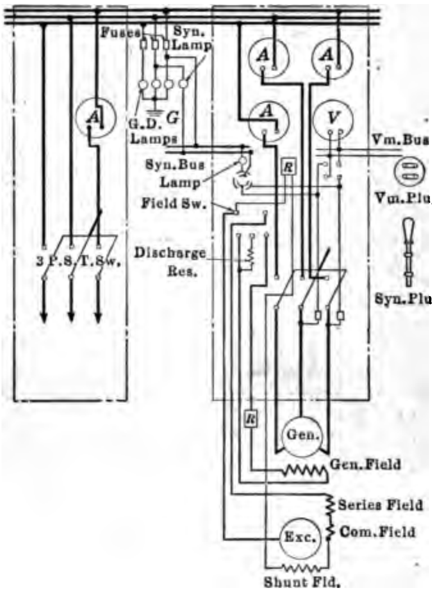



Fig. 293.—Diagram of Connections for Switchboard in Fig. 292.

panels for two three-phase generators, and *D* and *E*, feeder panels for two three-phase circuits.

Reference to the diagram of connections in Fig. 295 will show how the apparatus is connected, the switchboard wiring as viewed from the rear of the board being shown above and the station wiring below. The voltmeters and synchroscope are mounted on swinging brackets attached to the panel *A*, Fig. 294, and are wired to plug switches on the generator panels *B* and *C*. Either one ammeter per circuit with plug switch in each lead may be used, or one ammeter per

lead. Recording meters, if used, should be mounted on a separate panel. The field rheostats, also, are mounted apart from the panels, but are operated by handwheels on the board either by chain and steel cord transmission or electrically. For 2000 volts or more, ground detectors as described in Answer 610 and usually mounted near the bus-bars, are recommended, but for lower voltages incandescent lamp ground

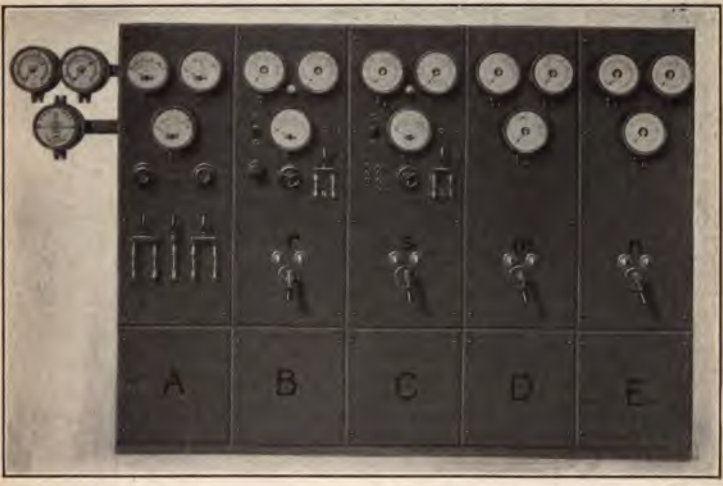



Fig. 294.—Three-Phase Switchboard for High-Voltage Service: One Exciter Panel, Two Generator Panels and Two Feeder Panels.

detectors connected in circuit direct or through potential transformers, depending upon the voltage, will be found satisfactory.

**766. Is there any way of compensating for the drop in voltage on an alternating-current circuit?**

Yes, this can be done by using a transformer "booster," connected as shown diagrammatically in Fig. 296. The high-tension winding *h* is connected across the mains near the generator *a*, and the low-tension winding *m* is connected in series with one of the line wires, *c e*. The connections are made so that the direction of current flow at any instant is

the same in the secondary winding of the transformer as in the line wire. This is indicated by the arrows in the diagram.

**767. How does the arrangement in Fig. 296 compensate for the drop in voltage?**

The voltage induced in the secondary winding of the

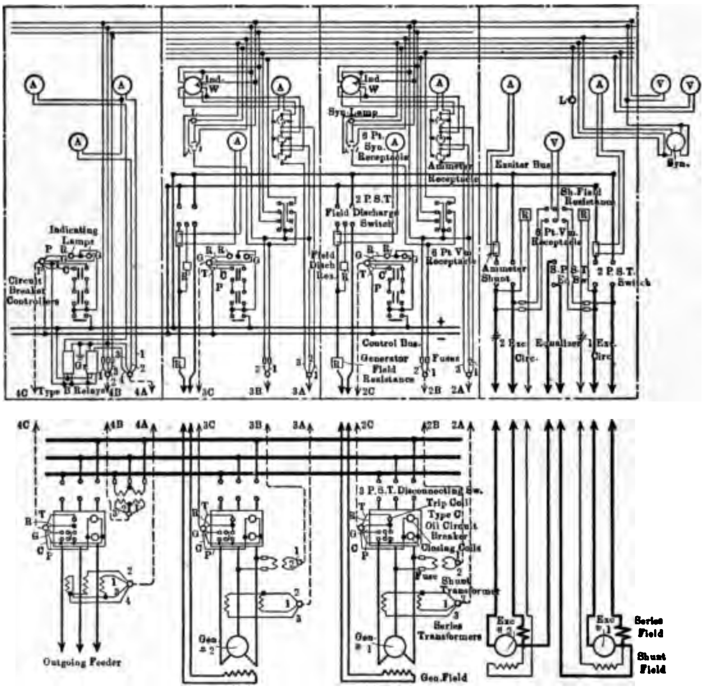


Fig. 295.—Wiring Diagram for Switchboard in Fig. 294 as viewed from Rear with Station Wiring Shown Underneath.

transformer is added to that of the generator. For example, suppose the generator to be giving 2300 volts at its terminals and the drop in the line to be 115 volts. If a transformer having a ratio of 20 to 1 be connected as shown in the diagram, its secondary voltage will be 115 volts, and this will be added to the voltage of the generator. Consequently,

while the voltage from *b* across to *c* will remain 2300, the difference of potential between *d* and *e* will be $2300 + 115 = 2415$ volts. This will make up the drop of 115 volts in the

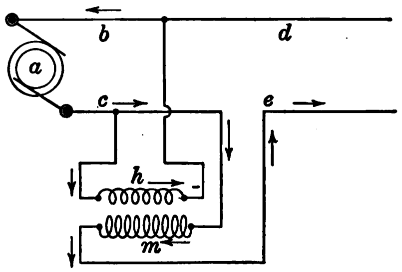



Fig. 296.—Diagram of Connections for a Transformer Voltage Booster.

line and raise the voltage at the far end to equal the generator voltage of 2300.

**768. Can a transformer booster be used on two-phase circuits?**

Yes; Fig. 297 is a diagram of booster connections for a

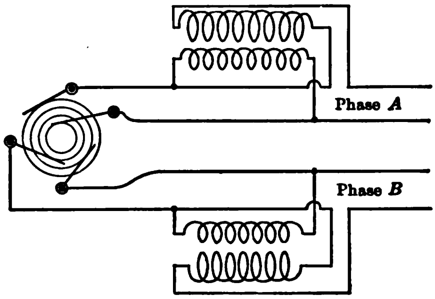



Fig. 297.—Connections of Transformer Boosters on a Two-Phase Circuit.

two-phase circuit. It is merely a duplication of the arrangement shown in Fig. 296, the two-phase circuit being the exact equivalent of two single-phase circuits.

**769. Are there any disadvantages to this method of compensating for the voltage drop in a line?**

The chief disadvantage is that the boosting transformer

raises the voltage by practically the same amount at all loads. Consequently the voltage at the end of the line is liable to be too high at small loads. This can be corrected, however, by making the transformer adjustable as to ratio; the secondary winding can be divided into a large number of sections and the terminals carried out to a switch by means of which more or less of the winding can be put in circuit, thereby varying the added voltage.

Another disadvantage is the size and cost of the transformer or transformers. They must have a power capacity equal to that of the alternator divided by its smallest ratio of transformation. Thus, if the alternator is a 5000-kilowatt machine and the transformer ratio is 10 to 1, minimum, the transformers must aggregate 500 kilowatts capacity.

**770. Is there any specially designed apparatus on the market for automatic voltage regulation on alternating-current circuits?**

Yes; a form of automatic voltage regulator for switchboard use is shown in place on a switchboard panel in Fig. 298. In the front and rear views of the panel there shown the regulator mechanism is enclosed in a glass case at *a*, and the rheostat with which the regulator mechanism is connected may be seen at *c*.

The desired voltage is maintained by rapidly opening and closing a shunt circuit across the exciter field rheostat. The rheostat is first turned in until the exciter voltage is greatly reduced and the regulator circuit is then closed. This short-circuits the rheostat through contacts in the regulator, and the voltage of the exciter and alternator immediately rise. At a predetermined point the regulator contacts are automatically opened and the field current of the exciter must again pass through the rheostat. The resulting reduction in voltage is arrested at once by the closing of the regulator contacts which continue to vibrate in this manner and keep the alternator voltage within the desired limits.

From no load to full load the maximum travel of the

only moving parts of the regulator—the vibrating contacts—is but 1/32 inch. One automatic voltage regulator may control the voltage of a system operating two or more alternators in parallel by a suitable arrangement of equalizing rheostats. In Fig. 298 the rheostat *e* is in the field circuit of the alternator.

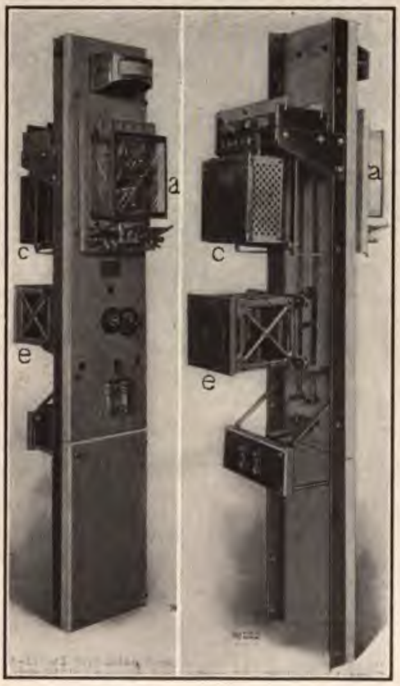



Fig. 298.—Automatic Alternating-Current Voltage Regulator mounted on Switchboard Panel; Front and Rear Views.

**771. How is a switchboard wired for two single-phase alternators to be operated in parallel?**

Fig. 299 shows the principal connections of the switchboard apparatus for operating two single-phase alternators, *a* and *b*, in parallel. At *c* is a synchronizing transformer, and at *d* and *e* are the lamps used in connection with *a*, the

principle of which has already been explained in Answer 407. The primary windings of the synchronizing transformer are connected in opposition to each other so that the synchronizing lamps, *d* and *e*, will be dark when the machines are in step. Until this condition has been brought about, one of the main switches, *f* and *g*,—that in connection with the incoming machine,—must be left open. It is always well when the connections are made as in Fig. 299 to have an extra lamp

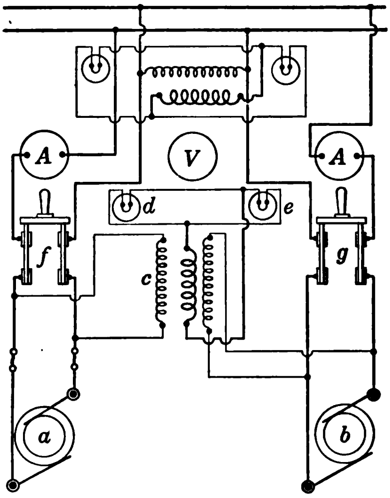



Fig. 299.—Switchboard Wiring for Two Single-Phase Alternators operated in Parallel.

connected in parallel with each synchronizing lamp; then if one lamp be burned out, the other will still indicate whether or not the alternators are in step. Though not absolutely necessary, it is preferable to have a voltmeter for each machine, especially if the alternators are to be thrown together while one is carrying a varying load.

**772. How should a switchboard be wired for operating two polyphase alternators in parallel?**

Fig. 300 is a diagram of the principal switchboard connections for operating two two-phase alternators *m* and *n* in

parallel. Since there is always a fixed relation between two or more phases developed by the same machine, it is not necessary to employ more than one synchronizer when throwing polyphase machines in parallel. One of the primary windings of the synchronizing transformer *c* is connected across the bus-bars *d* and *e*, and the other primary winding is wired to the corresponding phase of the incoming alternator *m*. A voltmeter for each machine is sufficient, but the connec-

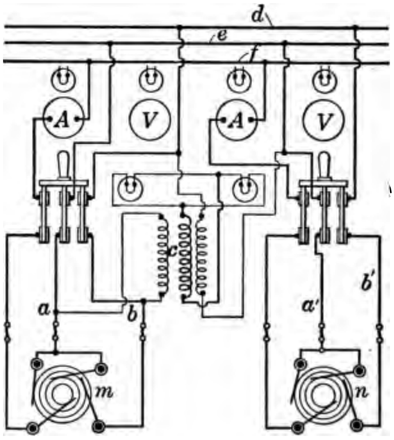



Fig. 300.—Switchboard Wiring for Two Two-Phase Alternators operated in Parallel.

tions should be such that when the two machines are running in multiple there will be one voltmeter on either phase; and that when only one machine is in operation it will be possible to use either voltmeter in connection with that one machine. It is also best to connect the transformers that feed the pilot lamps and voltmeters between the switches and the alternators so that there will be light and a proper indication of voltage before the switches are closed.

**773. Is the synchronizing transformer connected permanently to the one alternator?**

No; in practice the primary transformer winding on the

left in Fig. 300 is connected to plug switches, by means of which it may be connected to any one of all the generators that are intended to operate on the bus-bars *d, e, f*. A switch is also provided for connecting the other primary winding to the bus-bars for synchronizing, and disconnecting it when not synchronizing. This winding, however, is not intended to be connected to anything but the bus-bars *d* and *e*.

**774. What general considerations govern the arrangement of bus-bars and switches on an alternating-current switchboard?**

When more than one set of bus-bars are installed, it is well to provide each out-going work circuit with switches by means of which it may be connected to more than one set of bus-bars; it is likewise important to be able to connect any machine to any set of bus-bars. The cable plug-board, Fig. 227, is a most flexible arrangement for this purpose. The circuits should be grouped together in such a manner that those requiring the same potential are connected to one pair of bus-bars. If some of the circuits require a higher voltage than the others, they should be kept apart and confined to one machine. Arrangements should be made so that the controlling switches, etc., in the main circuit need be handled as little as possible.

# STATION WIRING

**775. What wiring is included under the head of station wiring?**

The wiring between the generators and the switchboard, and the wiring for the station lights.

**776. How may the conductors running between the generators and the switchboard be supported?**

One method consists in fastening them overhead to horizontal beams put in at intervals for that purpose. This arrangement is similar to that for outside line work where only moderate care is needed. It is merely necessary to support the wires on good insulators and to maintain a sufficient distance between them and the supporting surface, which distance varies with the voltage. Up to 300 volts, the distance from the supporting surface should be ½ inch, and between wires 2½ inches; for 300 to 550 volts, 1 inch from the supporting surface and 4 inches between wires. The principal objection to this method of wiring is, usually, more or less vibration, which has a tendency to shake the wires loose. This will cause them to stretch and the ties to give more or less, until in time all of the wires appear as if they had been carelessly put up.

Another method of supporting the conductors consists in running them along the walls and ceiling of the station. By doing neat work, spacing the insulators equally, avoiding kinks in straight runs, and making all curves gracefully, the installation may by this method be made to present a good appearance. One objection is that the wires usually have to be much longer to reach between the generators and the switchboard than would otherwise be the case.

**777. Are lead-covered cables used in this work?**

They are used in damp locations to protect the insulation of the conductors from moisture, and where the cable is exposed to mechanical injury to protect it from harm. In such cases the cables are usually supported along the walls by

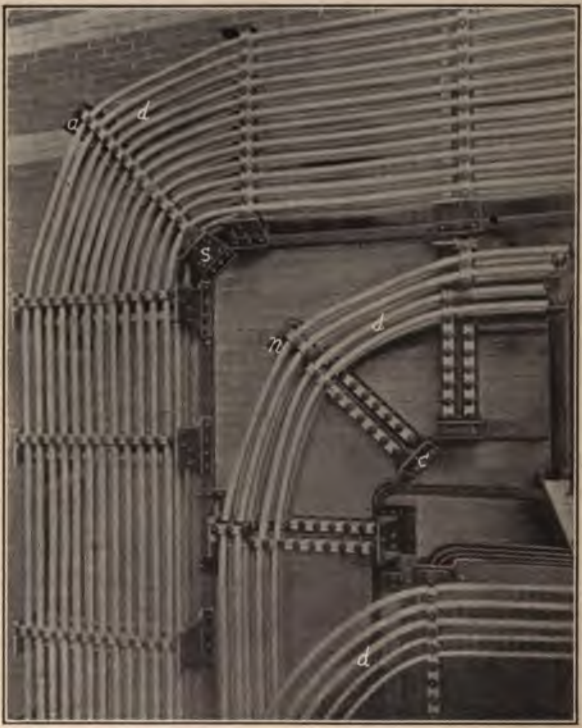



Fig. 301.—Method of supporting Lead-Covered Cables to Wall of Station by means of Cable Racks.

iron frames or racks, as shown at *a s, n, c*, etc., in Fig. 301, where the cables may be seen at *d, d*, etc. The racks are securely bolted to the wall and should be of sufficient strength to safely support the weight of the cables. They may be made of any length, and can be so constructed that three or four rows of cables may be placed on top of each other. It is

important that the racks be spaced sufficiently close to prevent the cables from sagging. It is also necessary that the bends formed in rounding corners be not made too short.

**778. Is there any objection to having the conductors run through the station?**

Yes; wiring in a station is likely to be in the way of a traveling crane, if there is one, and it invariably presents obstacles when repairs or changes are to be made in the plant.

**779. How may these objections be overcome?**

By placing the conductors under the floor; there they are usually out of the way of everything, and are not apt to be interfered with.

**780. How are the conductors arranged when put beneath the floor?**

When the building is of wood and there is space between the floor and the ground, ordinary cross-arms and insulators may be fastened under the floor and the wires supported on them. When there is no such open space, a special passage or subway under the floor may be constructed of brick or concrete; this insures protection from fire, and prevents the wires from being injured by water or other destructive agencies. When such a subway is to be used, it is best to have it included in the building contract and specifications, for that will insure better construction at less expense.

**781. How should a subway for station wiring be built?**

A simple and serviceable subway for this purpose is illustrated in Fig. 302. The distance between the walls *n* and *n* should not be less than 33 inches, but the depth may vary according to conditions. In the case shown, the depth is about 6 feet. When there are only a few conductors less space is required, and when there is a possibility of moisture accumulating there should be ample space between the wires and the floor *h*. The top may be floored or bricked over; manhole covers, as shown at *m*, should be provided at intervals. It is preferable, however, to have the cover made so that any part, or all of it, may readily be removed.

**782. How are the subway supports for the wires constructed and arranged?**

The supports *b*, Fig. 302, are made of wood, about 3 inches square. They should be well coated with an insulating and


Fig. 302.—Subway for Station Wiring.

fireproof paint. The distance between the supports depends upon the number and the size of wires to be installed.

**783. How are the insulators attached?**

The kind of insulators used determines the manner of mounting them. In the case illustrated, the wires are attached to ordinary porcelain insulators such as are commonly employed for direct-current work, and these are screwed to the uprights. The insulators should hold the wires firmly so that they cannot slide in either direction.

**784. How should the wires be installed?**

In placing the conductors in position, the reel containing the wire should be taken to either end of the run, for instance, the switchboard end; the wire may then be drawn through and fastened to the generator terminals. After having been properly tied to the first insulator at the generator end of

the subway, the wire should be drawn taut all along, and securely fastened to each insulator in succession, working toward the switchboard end of the run.

**785. How are the conductors brought up for connection to the switchboard or the generators?**

Through holes in the floor, as shown in Fig. 303. To protect the conductors from injury, water, etc., at the floor level, they are generally led up through the floor in iron pipes, as shown at *b, d,* etc., in the illustration.

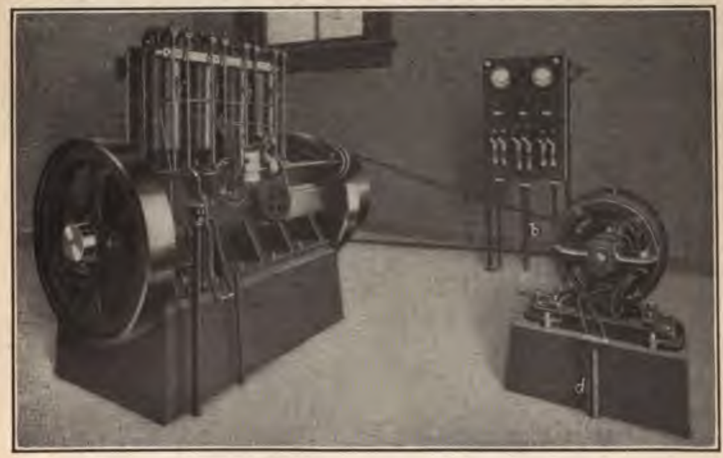



Fig. 303.—Station Interior, showing how Conductors are brought up through Floor in Iron Pipes for connection with Switchboard and Generator.

**786. Where is it customary to place the station lightning arresters?**

It is quite common practice to place them on the walls of the station near the point where the wires enter,—one arrester to each overhead circuit connected to the station. When a small number of arresters are used, they should all be placed inside the station, but with a large number they may be placed both inside and outside. In the latter case they must not, in any way, be exposed to moisture, but should be properly enclosed in an iron casing.

**787. What other precautions are necessary in connection with the installation and wiring of the lightning arresters?**

They must not be near combustible materials. Kinks, coils and sharp bends in the wires between the arresters and the outside lines must be avoided as far as possible. A good permanent ground connection is absolutely necessary, and the arrester should be connected to it by a straight wire or conductor as explained in Answers 709 and 710.